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**SURVEY OF OUTDOOR AIR CONDITIONER NOISE**

**FINAL REPORT - Revised February 27, 1991**

**RAC Report # 458G**

**Report prepared for:**  
**Research and Technology Branch**  
**Ontario Ministry of the Environment**

**Report prepared by:**  
**J.S. Bradley of the National Research Council Canada**  
**and the**  
**Heating, Refrigerating and Air Conditioning Institute of Canada**

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## Executive Summary

This report presents the results of a survey of both subjective and objective ratings of outdoor domestic air conditioner noise. The survey was carried out in the Metro Toronto area, and both subjective and objective data were successfully obtained for 550 subjects. Subjects were selected to include the four combinations of low and high ambient noise level sites with owners and non-owners of air conditioners. In many cases, air conditioner noise levels were not substantially higher than existing background noise levels, making it difficult to obtain strong relationships between the air conditioner noise stimulus and subjective responses. Some highlights of the results include:

- (1) In spite of the inherent difficulties described above, adverse responses were significantly related to objective noise measures. While there were many statistically significant relationships between objective and subjective responses, the variance explained was often quite small and one should be careful not to assume these results to be more precise than is really justified.
- (2) Adverse responses were more strongly related to signal/noise ratios than to the measured noise levels.
- (3) Below 50 to 55 dB(A) (as measured at the property line), annoyance was not systematically influenced by air conditioner noise level. Similarly, below a signal/noise ratio of about +5 dB(A), annoyance was not related to measured noise levels.
- (4) At sites with higher ambient noise, subjects were less annoyed by their neighbours' air conditioner noise by the amount expected due to the decreased signal/noise ratio.
- (5) Owners of air conditioners were less annoyed by air conditioner noise by an amount equivalent to 7 dB(A) lower air conditioner noise levels.
- (6) The ARI 275-84 prediction scheme was not found to be particularly accurate. Measured levels close to the air conditioner source were on average several decibels lower than predictions. Similarly, measured values at the facade of the neighbours' home were on average not predicted well. In most cases there was a quite large scatter in the comparison of predicted and measured values.

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Appendix 1. The Questionnaire

Appendix 2. Statement of Work

## 1. Introduction

This is the final report of a survey of both sound levels and subjective attitudes to residential air conditioner noise levels. The work was a joint project of the National Research Council (NRC), the Ontario Ministry of the Environment (MOE), and the Heating Refrigerating and Air Conditioning Institute of Canada (HRAI). Support for the field measurements was also provided by the City of North York, the City of Toronto, Toronto Hydro, the Ontario Home Builders' Association, Ontario Hydro, and the Ontario Ministry of Housing. MOE was responsible for finding appropriate measurement sites and for all field measurements. NRC planned the experimental design and carried out all analyses of the data including the preparation of this report.

The purpose of the survey was to consider the question of acceptable limits for outdoor residential air conditioner noise. The terms of agreement of the contract under which this work was performed are included in Appendix 2. The principal objectives of the project were:

- (a) to quantify the relationship between subjective response to neighbours' air conditioner noise and the measured noise levels of these air conditioners;
- (b) to provide information to support the setting of acceptable limits for outdoor air conditioner noise levels;
- (c) to examine how local ambient noise and ownership of an air conditioner influence adverse reactions to air conditioner noise;
- (d) to consider the influence of other non-noise factors on adverse reactions to neighbours' air conditioner noise;
- (e) to compare measured air conditioner noise levels with predictions based on the ARI 275-84 procedure.

It was initially planned that all measurements would be made during the summer of 1989 and that analyses of the data would be completed in the fall of 1989. The first measurement phase was not completely successful and a second phase of measurements was carried out during the summer of 1990 at sites in the Metro Toronto area. The final data set included questionnaire responses along with air conditioner and ambient noise measurements for 550 subjects. This report describes the analysis of this data.

## **2. Methodology**

### **2.1 Experimental Design**

It had been suggested that residents in noisier areas might be more tolerant of noise from their neighbours' air conditioner, and that subjects who owned air conditioners would be less disturbed by the noise from their neighbours' unit. The experimental design included a subject selection procedure that would make it possible to determine the effects of ambient noise levels and ownership of an air conditioner on adverse responses to air conditioner noise.

The goal was to interview a total of 600 subjects from four equal groups. The groups were to be the four combinations of high and low ambient noise with owning and not owning an air conditioner. Thus, it was hoped to obtain 150 subjects in each of these four groups. Of course, each subject had to have at least one neighbour with a central air conditioner or heat pump. Subjects also had to be at least 18 years of age, and it was hoped to get an approximately equal number of males and females.

Potential subjects first received an introductory letter from the Ontario Ministry of the Environment describing the survey as concerning particular aspects of the neighbourhood environment, and encouraging them to participate. Shortly after receiving the introductory letter, subjects were approached by an interviewer, and an interview was carried out at the convenience of the subject. No mention was made that the survey concerned air conditioner noise until after the interview. However, after a few questions, subjects were asked if any of their immediate neighbours had a central air conditioner. If not, the subject was thanked and the interview terminated.

After the interview was successfully completed, permission to make noise measurements was requested. These were made as soon as possible after the completion of interviews in that particular area. As a final gesture, each subject was given a thank you letter expressing appreciation for their help, revealing that the survey was focussed on air conditioner noise, and giving the names of the three main sponsoring groups.

### **2.2 The Questionnaire**

The questionnaire was administered directly to subjects in their homes by a trained interviewer. The interviewer wrote the coded responses on the questionnaire form. Most responses were in the form of seven-point response scales, and subjects were shown a response card from which to select a numerical response. The card included the integer numbers from 0 to 7; the value "0" was labeled

"Not Applicable", the value "1" was labelled "Not at all"; the value "4" was labelled "Medium", and the value "7" was labelled "Very". By not labeling intermediate values of the seven-point scale, it was hoped that subjects would linearly interpolate between the extremes of the end values and valid interval scale response data would be obtained. Where subjects refused to answer particular questions (e.g. concerning income), a "-1" response was to be entered.

A copy of the questionnaire is included in Appendix 1. The first two questions in the interview were open-ended questions about things subjects liked and didn't like about their neighbourhood. This gave respondents a chance to spontaneously mention air conditioner noise without any prompting by more direct questions. This was followed by questions concerning how considerate their neighbours were thought to be, and whether an immediate neighbour had a central air conditioner or heat pump.

This initial section was followed by the main body of the questionnaire that included direct questions concerning how often they heard or were annoyed by various environmental noises. These included: road traffic noise, aircraft noise, train noise, and residential air conditioner noise. This block of questions was repeated four times. The questions were asked for day- and night-time conditions as well as for the subject being indoors or outdoors. This was followed by questions concerning possible sleep disturbance by each type of environmental noise.

The final section of the questionnaire gathered the usual socio-economic information about respondents. Questions concerned the total family income, the subject's years of formal education, the subject's age, the number of adults and the number of young people in each home. They were also asked whether air conditioner noise was more disturbing in a particular room, whether they owned a central or window air conditioner, and how much extra they would pay if buying a \$2,000.00 central air conditioner for a very quiet model. The interviewer also recorded whether the subject was male or female, whether they appeared to have any hearing problems, and whether their home was a row house, semi-detached, or a detached home.

## 2.3 Noise Measurements

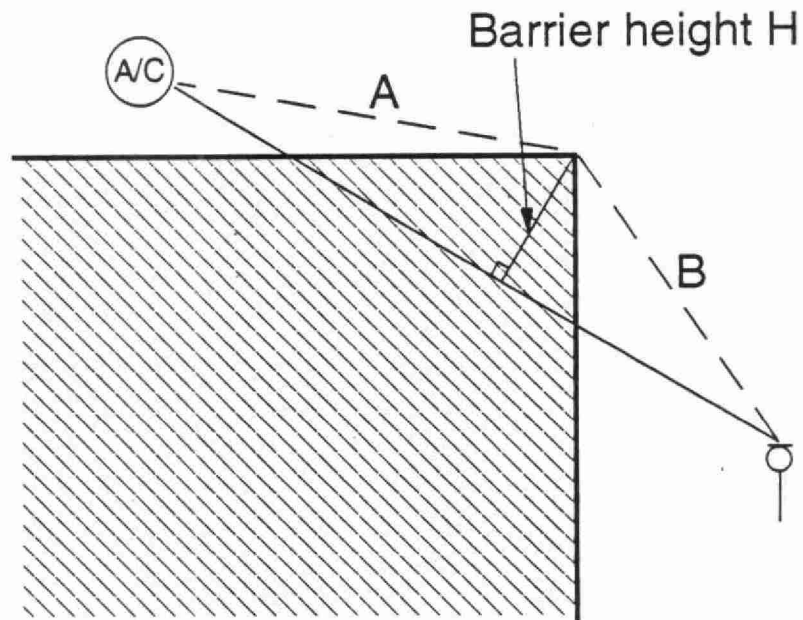
The noise measurement data were first entered onto sheets attached to the subjects questionnaire responses. Integrated A-weighted sound level measurements were



made at seven positions near each air conditioner. Each measurement was made at a height of 3 to 4 feet above the ground and consisted of a 30 second integrated level. Three measurements were made at positions 6 feet from the air conditioner unit when it was operating. Additional measurements were made at the property-line, at the facade of the neighbours' home, and at the neighbours' patio. A final measurement was made with the unit not operating.

The make, model, and serial number of the unit were recorded where possible, and several distances were recorded. Figure 1 illustrates a typical plan where there is not a direct line-of-site path from the air conditioner to the measurement position. Each of the distances "A", "B", and the perpendicular height "H" were measured and recorded. Where there was no barrier screening at the measurement position, a single distance was entered as distance "A".

Figure 1. A typical site plan example illustrating the measured distances "A" and "B" as well as the barrier height "H".



The air conditioner unit was assumed to always be mounted on one surface, either the ground or a wall. The number of other surfaces within 10 feet of the unit was also recorded for use in the ARI 275-84 prediction scheme. Finally, a facade correction term was also noted if the microphone was at or near the facade of a home. If the microphone was on the facade, a 6 dB(A) correction was included; if the microphone was within 10 feet of a surface

that would reflect sound to the microphone, a 3 dB(A) correction was made. Noise levels and the associated information could be recorded for up to three nearby air conditioners.

Ambient noise levels were measured using a miniature noise logger that recorded an  $L_{eq}$  value for each minute of a complete 24 hour period. From these one-minute  $L_{eq}$  values, day-time (7:00 AM to 10:00 PM), night-time (10:00 PM to 7:00 AM), and complete 24-hour  $L_{eq}$  values were calculated. Finally, the noise measurement personnel noted the two most obvious sources of environmental noise at each home.

### 3. The Survey Sample

#### 3.1 Acoustical Data

Two types of noise measurement data were obtained as part of the survey. Integrated A-weighted sound levels were measured in the vicinity of the neighbours' air conditioner and longer term environmental noise measurements were made near to the road in front of each home.

The three measurements close to the air conditioner unit were combined to give a single source-level measurement. Data could be entered for up to three different neighbouring air conditioner units for each survey respondent. In practice, data were never entered for a third unit, and in only 38 cases were there data for a second air conditioner unit. For 550 subjects there were noise level data for at least one air conditioning unit.

Table 1 summarizes the obtained noise data and associated distances. This table includes the mean values of each parameter as well as the standard deviations, minima, maxima and the number of values. It is seen from this table that for the first neighbours' air conditioner unit, 551 source level measurements were obtained; of these, 550 were also measured at the property-line, 508 at the respondents facade, and 550 at the respondents patio. Of these measurements, a few did not have a distance "A". There were relatively few cases where some screening occurred. At the property-line positions, only 6 cases were screened; at the facade, 22 were screened, and at the respondents patio only 6 were screened.

Table 1 also shows that only 38 second air conditioning units were measured. None of these included barrier



screening effects. Mean levels for the second units were similar to those for the first units.

Table 1. Summary of measured noise level values and associated distances.

| Variable                          | Mean | Std Dev | Minimum | Maximum | N   |
|-----------------------------------|------|---------|---------|---------|-----|
| <u>Unit No. 1</u>                 |      |         |         |         |     |
| Source level, dB(A)               | 64.3 | 3.0     | 54.0    | 72.5    | 551 |
| Property line level, dB(A)        | 60.1 | 4.8     | 45.0    | 74.0    | 550 |
| Distance A, feet                  | 13.9 | 9.3     | 3.0     | 50.0    | 549 |
| Distance B, feet                  | 4.0  | 4.7     | 1.0     | 15.0    | 11  |
| Barrier height, feet              | 4.2  | 4.3     | 1.0     | 12.0    | 6   |
| Facade level, dB(A)               | 58.3 | 4.7     | 48.0    | 76.0    | 508 |
| Distance A, feet                  | 17.7 | 10.7    | 4.0     | 74.0    | 507 |
| Distance B, feet                  | 10.4 | 5.8     | 1.0     | 23.0    | 25  |
| Barrier height, feet              | 4.4  | 3.9     | .8      | 15.0    | 22  |
| Patio level, dB(A)                | 55.8 | 3.9     | 45.0    | 67.0    | 550 |
| Distance A, feet                  | 25.8 | 11.4    | 8.0     | 99.9    | 549 |
| Distance B, feet                  | 4.6  | 5.8     | 1.0     | 21.1    | 13  |
| Barrier height, feet              | 3.2  | 2.4     | .5      | 6.5     | 6   |
| Background level, dB(A)           | 53.5 | 3.9     | 44.0    | 66.0    | 550 |
| Distance A, feet                  | 22.1 | 13.6    | 5.2     | 99.9    | 546 |
| <u>Unit No. 2</u>                 |      |         |         |         |     |
| Source level, dB(A)               | 64.1 | 2.7     | 60.0    | 69.0    | 38  |
| Property line level, dB(A)        | 60.3 | 4.7     | 52.0    | 70.0    | 38  |
| Distance A, feet                  | 14.8 | 9.8     | 3.0     | 37.0    | 38  |
| Facade level, dB(A)               | 58.4 | 4.7     | 44.0    | 67.0    | 37  |
| Distance A, feet                  | 19.0 | 9.1     | 6.0     | 41.0    | 37  |
| Patio level, dB(A)                | 56.2 | 3.4     | 50.0    | 66.0    | 38  |
| Distance A, feet                  | 28.1 | 11.7    | 10.0    | 51.0    | 38  |
| <u>Environmental Noise levels</u> |      |         |         |         |     |
| Day time $L_{eq}$ , dB(A)         | 61.2 | 3.3     | 50.0    | 71.0    | 599 |
| Night time $L_{eq}$ , dB(A)       | 54.5 | 3.5     | 47.0    | 65.0    | 599 |
| 24 hour $L_{eq}$ , dB(A)          | 59.7 | 3.2     | 53.0    | 69.0    | 599 |

Ambient environmental noise was described in terms of A-weighted  $L_{eq}$  values obtained from one 24-hour measurement at each location. These values are also

summarized in Table 1.  $L_{eq}$  values were entered for all 599 subjects from measurement positions that were representative of conditions at their home. The overall 24-hour  $L_{eq}$  varied from 53 to 69 dB(A), with an average of 59.7 dB(A).

The distribution of measured A-weighted air conditioner noise levels for each first air conditioner unit were plotted for each measurement position. These are shown in Figures 2 to 5 for the source level positions, the property-line positions, the facade positions, and the patio positions, respectively. Each plot also includes the distribution of background noise levels with the unit not operating. The source level values, shown in Figure 2, were well above the background levels (the means are different by 10.8 dB(A)) and thus these measurements were not greatly influenced by the existing background noise levels. However, the air conditioner noise levels at other positions further away from the unit were often close to the background noise levels. At the respondents' property-lines, mean air conditioner noise levels were only 6.6 dB(A) above the mean background level; at the facades, mean measured levels were only 4.8 dB(A) above mean background levels; and at the patios, mean air conditioner noise levels were only 2.3 dB(A) above the mean background noise levels.

Figure 2. Distribution of measured air conditioner noise levels at the source compared to the distribution of measured background noise levels.

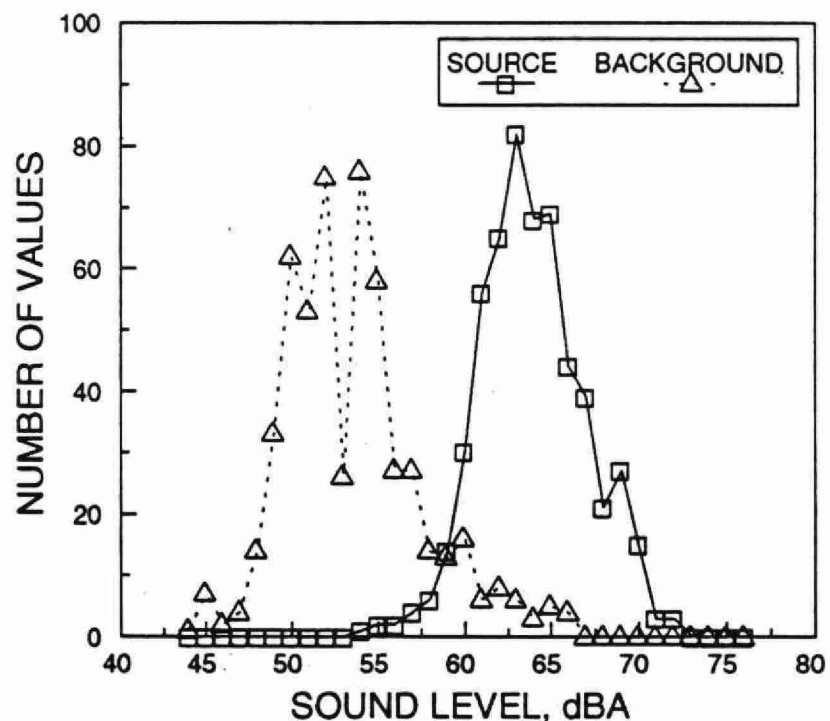


Figure 3. Distribution of measured air conditioner noise levels at the property line compared to the distribution of measured background noise levels.

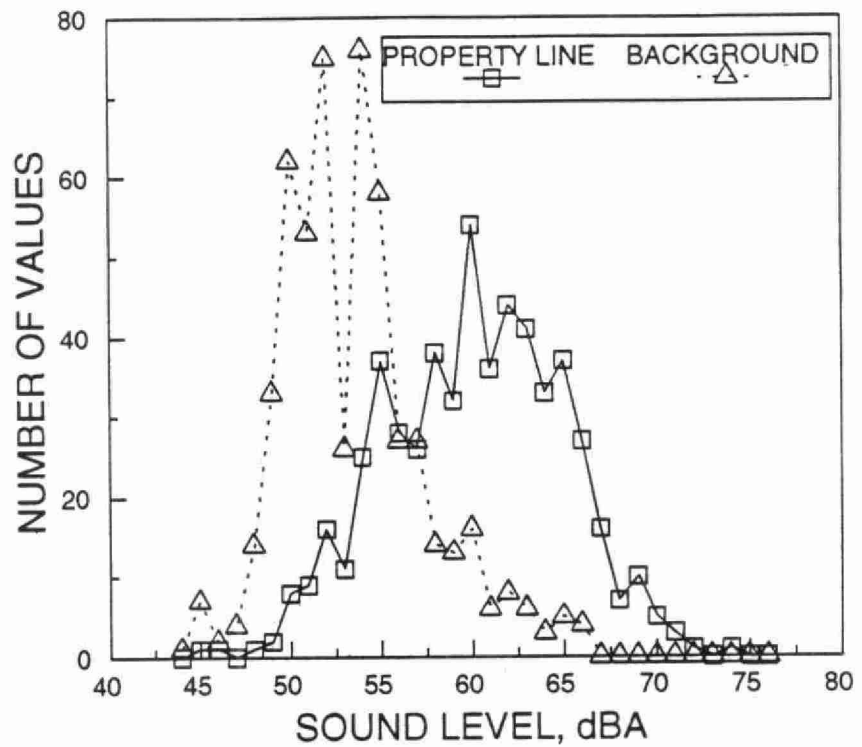


Figure 4. Distribution of measured air conditioner noise levels at the facade compared to the distribution of measured background noise levels.

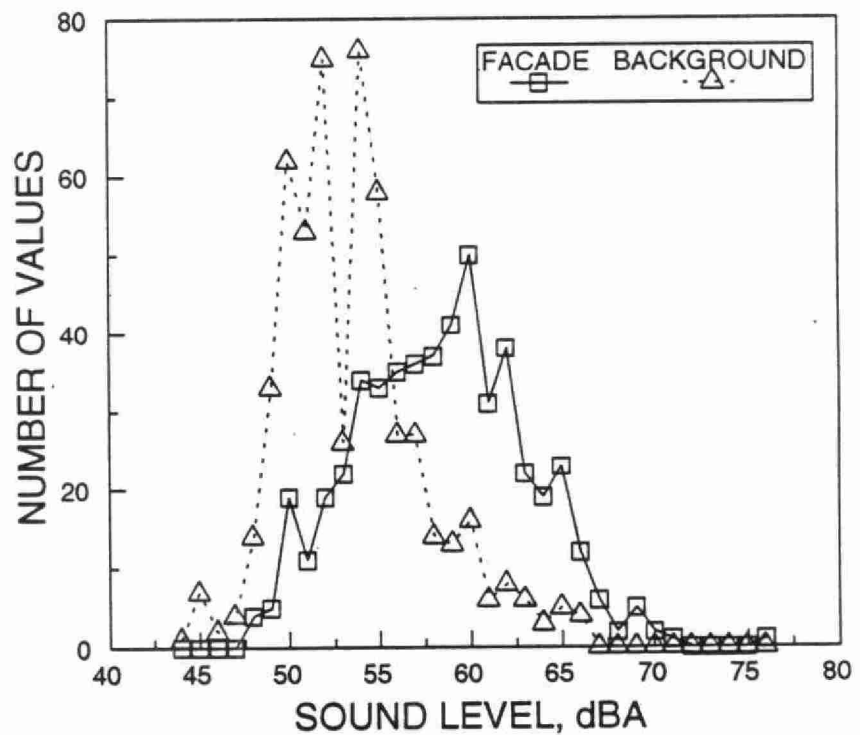
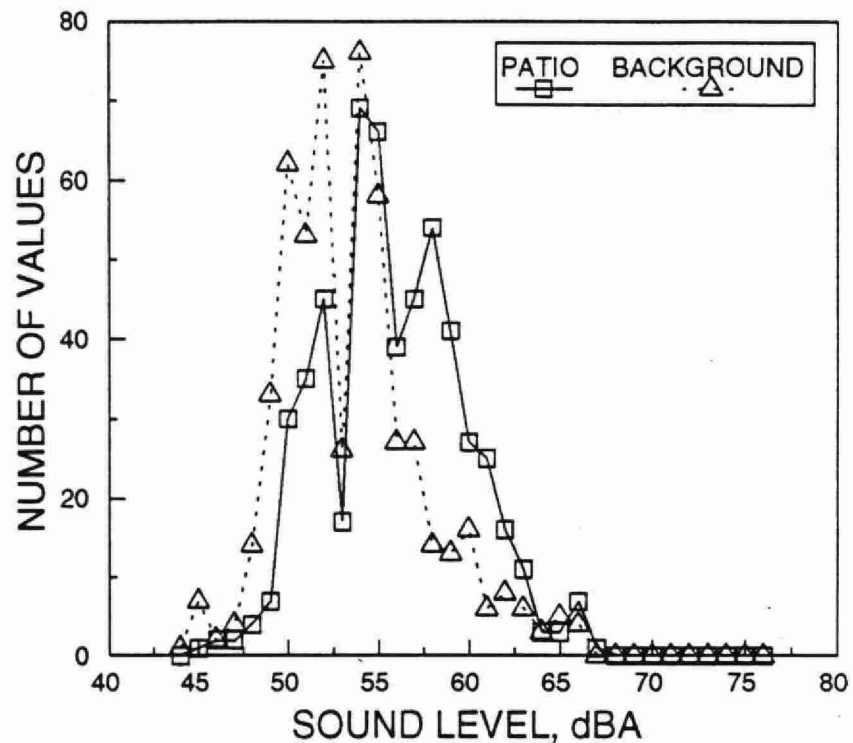


Figure 5. Distribution of measured air conditioner noise levels at the patio compared to the distribution of measured background noise levels.



These results suggested two basic problems would be encountered in analyzing this data. First, it is evident that many measured air conditioner noise levels would have been influenced by the existing background noise levels. Thus, the measured values will not always correctly represent only air conditioner noise levels. Second, subjective responses were solicited to air conditioner noises that in many cases may not have been completely audible.

### 3.2 Survey Data

Survey data was obtained from 599 respondents. Table 2(a) summarizes the socio-economic description of the survey sample. On average, there were 2.33 adults (18 or older) per home and 1.07 young people. The average age of respondents was 40.7 years, the average family income was \$45,900.00 and the average number of years of education of subjects was 14.3. The standard deviations of these variables, also shown in Table 2(a), are quite large and indicate that there was a broad range of ages, incomes, and years of education included in the survey sample.

Table 2(b) shows the break-down of the survey sample by sex, reported hearing problems, and housing type. There was a small bias towards female respondents, but this was a very small effect that is not expected to influence the other survey responses. Only 21 of the 599 subjects

were reported to have hearing problems. Almost 80% of the subjects were in detached homes. While 95 subjects lived in semi-detached homes, only 25 lived in row housing. Thus, the survey results will tend to represent conditions in detached or semi-detached housing.

Table 2(a). Means and standard deviations of socioeconomic survey variables.

| Variable              | Mean        | Std Dev     | N   |
|-----------------------|-------------|-------------|-----|
| No. adults/home       | 2.33        | .91         | 599 |
| No. young people/home | 1.07        | 1.37        | 598 |
| Age                   | 40.74       | 13.02       | 593 |
| Family income         | \$45,900.00 | \$24,400.00 | 488 |
| Years of education    | 14.31       | 3.59        | 575 |

Table 2(b). Breakdown of sample by sex, reported hearing problems and housing type.

|            |                  | Number | Percentage |
|------------|------------------|--------|------------|
| Sex        | Male             | 261    | 43.6       |
|            | Female           | 338    | 56.4       |
| Hearing    | Reported problem | 21     | 3.5        |
|            | No problem       | 577    | 96.3       |
| House type | Row              | 25     | 4.2        |
|            | Semi-detached    | 95     | 15.9       |
|            | Detached         | 478    | 79.8       |

Most survey data were directly elicited responses concerning whether subjects heard or were annoyed by various types of noises. The results are discussed in later sections with respect to measured noise levels. Some more general responses are included in this section.

Subjects were first asked about likes and dislikes concerning their neighbourhood to give them an opportunity to spontaneously mention their opinions concerning noise and in particular air conditioner noise without being specifically prompted to do so. No subjects spontaneously mentioned anything related to air conditioners as something they liked about their neighbourhood. However, 185 subjects spontaneously mentioned that they liked their neighbourhood because it was quiet, indicating that this was a real concern for them. One subject spontaneously mentioned air conditioner noise as something that was not liked about their neighbourhood. A further 171 subjects mentioned noise-related dislikes about the neighbourhood. Thus, there is substantial evidence that noise is a determining factor of neighbourhood quality, but there was no

evidence from these results that air conditioners were an important source of this noise.

Subjects were asked if the noise from their neighbours' air conditioner was more disturbing in a particular room. Although 367 responded that there were no differences, 109 found air conditioner noise most disturbing in their bedroom. There were 50 subjects who found the problem most severe in their living rooms, and smaller numbers for other types of rooms. There seems to be some importance to locating air conditioner units so that they are as far away as possible from bedrooms.

Of the 599 subjects, 331 reported that they owned central air conditioners and 129 said that they owned window air conditioners. Only 153 subjects had neither type of air conditioner and 446 subjects had one or both types. Thus, the respondents were not evenly split between owners and non-owners of air conditioners. There was a strong bias towards subjects owning air conditioning units.

Subjects were asked how much extra they would pay for a quiet unit when buying a \$2,000.00 central air conditioning system. The mean response was \$243.91, with a standard deviation of \$296.54. Although responses were quite varied, the mean trend indicated that subjects would pay a substantial amount extra (just over 12%) to obtain a quiet air conditioner.

Subjects were also asked whether they kept some windows open at the time of year that the survey was conducted. The survey was conducted in the middle of the summer, and 78% of respondents indicated that they did keep some windows open.

The noise measurement team noted two most obvious sources of neighbourhood noise. In 74% of the cases, road traffic noise was the major source of noise, and in 24% of the cases trains were the major source of noise. In only 0.5% of the cases was air conditioner noise considered to be the major source of neighbourhood noise, and in only 1% of the cases was it even the second most audible source of noise. Aircraft noise was the most prominent secondary source of noise.

### 3.3 Quality of the Data

The quality of the data from a survey such as the present one is very strongly dependent on a very serious and conscientious effort by the field personnel. The scatter in the survey results can be reduced by careful measurement and data entry techniques. MOE personnel went to

considerable effort to avoid and eliminate errors in the survey data and there was no evidence of any problems that might in any way bias the results.

There are problems of a quite different nature with the acoustical data. Unfortunately, the noise levels produced by air conditioners are often quite similar to ambient background noise levels. Thus, it is often difficult to measure air conditioner noise levels accurately without contamination from the ambient background noise. This also means that in some cases subjects are being asked to give responses concerning air conditioner noise that they cannot normally hear. When the noise levels cannot always be accurately measured and in some case subjects cannot normally hear the noises, correlations between objective and subjective measures must necessarily suffer. This is unfortunately the nature of the problem that this survey is trying to assess.

#### **4. Initial Individual Subject Analyses**

The bulk of the questionnaire was composed of questions that directly elicited response concerning how often subjects heard particular noises and how annoying these noises were. These questions were repeated for: (1) road traffic noise, (2) aircraft noise, (3) train noise, and (4) air conditioner noise. Subjects' responses were elicited for conditions when they were indoors as well as when they were outdoors. For both these indoor and outdoor situations, subjects were asked how often they heard the noises and how annoyed they were by the various noises both in the day-time and in the night-time. Thus, there were eight questions for each of the four types of noise.

As a first analysis, these responses were correlated with measured noise levels. Table 3. summarizes significant correlations ( $p < 0.01$ ) between air conditioner noise responses and measured air conditioner noise levels. Less significant correlations were not included in this table. Table 3. shows some significant but small correlation coefficients. Thus, although a number of results are highly significant, they do not explain a large portion of the variance in the subjective responses. Only day-time responses produced any significant correlation coefficients. Night-time responses were not significantly related to any of the noise measures in these initial results.



Table 3. Summary of significant correlations ( $p < 0.01$ ) between noise measures and air conditioner noise responses. Correlations were performed with the linear noise measure, with the noise measures squared and with the noise measures cubed.

| Noise Measure<br>dB(A) | Math Format | Indoors |       |       |       | Outdoors |       |       |       |
|------------------------|-------------|---------|-------|-------|-------|----------|-------|-------|-------|
|                        |             | Day     |       | Night |       | Day      |       | Night |       |
|                        |             | Hear    | Annoy | Hear  | Annoy | Hear     | Annoy | Hear  | Annoy |
| Source                 | linear      | .142    | -     | -     | -     | -        | -     | -     | -     |
|                        | square      | .144    | .101  | -     | -     | -        | -     | -     | -     |
|                        | cubed       | .146    | .104  | -     | -     | -        | -     | -     | -     |
| Property               | linear      | .149    | .124  | -     | -     | .140     | .116  | -     | -     |
|                        | squared     | .152    | .128  | -     | -     | .141     | .117  | -     | -     |
|                        | cubed       | .155    | .131  | -     | -     | .141     | .118  | -     | -     |
| Facade                 | linear      | .124    | -     | -     | -     | .111     | -     | -     | -     |
|                        | squared     | .131    | .106  | -     | -     | .114     | -     | -     | -     |
|                        | cubed       | .138    | .113  | -     | -     | .118     | -     | -     | -     |
| Patio                  | linear      | -       | -     | -     | -     | -        | -     | -     | -     |
|                        | squared     | -       | -     | -     | -     | -        | -     | -     | -     |
|                        | cubed       | -       | -     | -     | -     | -        | -     | -     | -     |
| Back-ground            | linear      | -       | -     | -     | -     | -        | -     | -     | -     |
|                        | squared     | -       | -     | -     | -     | -        | -.101 | -     | -     |
|                        | cubed       | -       | -     | -     | -     | -        | -.105 | -     | -     |
| $L_{eq24}$             | linear      | -       | -     | -     | -     | -        | -     | -     | -     |
|                        | squared     | -       | -     | -     | -     | -        | -     | -     | -     |
|                        | cubed       | -       | -     | -     | -     | -        | -     | -     | -     |

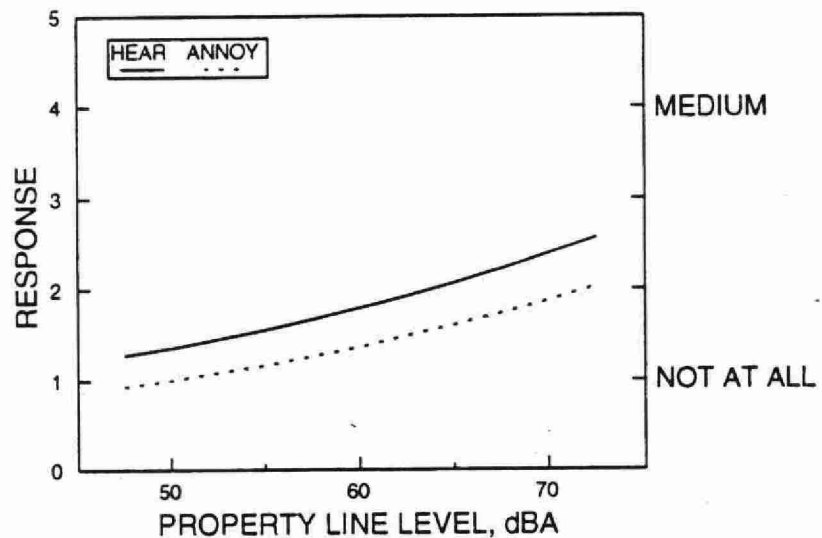
Correlations with property-line air conditioner noise levels tended to produce the highest correlations. Some correlations with the air conditioner source levels and the facade noise levels were also significant. Correlations with patio air conditioner noise levels and with the environmental noise  $L_{eq}$  values were not significant. Only outdoor day-time annoyance response were related to the background noise levels; as might be expected, these correlation coefficients were negative, indicating that higher background noise levels were desirable because they masked the air conditioner noise.

This table includes correlations with the linear noise measures as well as the square and the cube of the noise levels. Correlations with the cube of the noise measure were always a little stronger. Figure 6 plots best fit regression lines of the indoor day-time air conditioner noise responses versus the cube of the property-line noise levels. Both responses (for how often air conditioner noise was heard, and how annoying it was) are plotted. The curves increase from approximately the minimum



response of 1 for the lowest noise levels (45 to 50 dB(A)) to a mean response of about 2 for the highest noise levels (70 to 75 dB(A)). They illustrate that on average subjects did not ever report hearing air conditioner noise very often nor did they ever find it very annoying.

Figure 6. Best fit regression lines for the day-time indoor responses concerning how often they hear their neighbours' air conditioner and how annoyed they are by this noise.



The similar responses concerning road traffic noise, aircraft noise, and train noise were correlated with  $L_{eq}$  values. Seven of the eight responses concerning road traffic noise were significantly positively correlated with  $L_{eq24}$  values and produced correlation coefficients varying between 0.126 and 0.212. Aircraft noise responses were not significantly related with any noise measures. Train noise responses were found to be negatively related to measured  $L_{eq24}$  values. This apparently spurious result was due to the fact that the sites where train noise was audible had, on average, lower  $L_{eq24}$  values.

Most responses concerning road traffic noise were significantly related to the measure of ownership of an air conditioner. These correlations indicated that owners of air conditioners were less disturbed by road traffic noise, presumably because the air conditioner made it more difficult to hear the traffic noise.

## 5. Individual Data - Methods to Improve Correlations

### 5.1 Composite Response Scales

Because the responses to several questions relate to subjects' awareness and annoyance to air conditioner noise, it was possible to consider forming composite response scales. These were formed using two different techniques. Most simply, all responses related to air conditioner noise were added together to create one composite scale score. Composite scales were also obtained using factor analysis of the responses. All responses that were found to cluster together in the factor analysis were added together to form a composite scale score. It was hoped that these composite scale scores would be more robust in that they would be significantly related to more noise measures than the individual responses and that correlation coefficients might be a little larger.

First, two composite air conditioner noise response scales were formed by adding the responses of all four questions concerning how often air conditioner noise was heard and also the four questions concerning how annoying it was for indoors, and outdoors as well as for day and night-time. These two composite scales, labelled "Hear" and "Annoy", were then correlated with the various air conditioner noise level measurements. Both composite scales were significantly related ( $p < 0.01$ ) to the property-line noise levels; the "Annoy" scale was also negatively related to the measured background noise levels. The correlation coefficients were smaller than for some individual responses.

Next, a single composite response scale was formed by summing the responses of the two previous scales ("Hear" and "Annoy"). This combined air conditioner response scale was again significantly related to the property-line and background noise levels but less strongly than the best individual responses.

Further composite response scales were created by adding responses concerning sleep disturbance to the other air conditioner noise responses and also by selectively choosing smaller groups of "better" responses. In no case was a composite scale created that was more strongly related to air conditioner noise level values.

To more rigorously search for a useful composite response scale, factor analysis was used to determine which responses clustered together. All of the major survey responses were entered into a factor analysis and the factors rotated by varimax. The resulting second factor was clearly an air conditioner noise response grouping.

The responses that loaded heavily onto this factor were the same eight responses concerning hearing and being annoyed by air conditioner noise as well as the questions concerning sleep disturbance by air conditioner noise. Thus, the composite response scale suggested by the factor analysis was as expected and had already been considered. This factor analysis does confirm that subjects did appear to interpret the questionnaire as expected and all responses concerning air conditioner noise were related to each other.

It was concluded that it was not possible to form a composite response scale that usefully increased the strength or the number of correlations with the various air conditioner noise level measurements. However, the "Hear" and "Annoy" scales scores were used in a limited number of analyses.

## 5.2 Selecting Data According to Signal/Noise Ratio

Because background noise levels were relatively high compared to air conditioner noise levels, it was often difficult to accurately measure air conditioner noise levels; in many cases subjects may not have normally been able to hear the neighbours' air conditioner. The mean measured background noise level from Table 1 was 53.5 dB(A). This is higher than some regulated property-line limits for air conditioner noise levels (which in some municipalities are as low as 45 dB(A)). For the present data only 2% of the background noise level measurements were equal to or less than 45 dB(A). Thus, at almost all locations it would have been impossible to check for compliance with a 45 dB(A) maximum during the day-time.

Environmental noise  $L_{eq}$  values in Table 1 were approximately 5 dB(A) lower at night. From this one might guess that the night-time background noise levels would be approximately 5 dB(A) lower at night. This would lead to an average night-time background level of about 48 dB(A). Thus, it would probably not be possible to check for exceedance of 45 dB(A) even at night at all locations.

The data in Figures 2 to 5 suggested that the amount that air conditioner noise levels exceeded the ambient background noise level varied from position to position. To more clearly describe conditions at each measurement point, distributions of signal/noise ratios were plotted for each measurement point. These are shown in Figures 7 to 10 for measurements at the source, at the property-line, at the facade, and at the patio.

Here, and throughout this report, signal/noise ratio is the ratio of the measured air conditioner sound energy to the ambient sound energy, expressed in decibels. If the sound is measured in decibels, the signal/noise ratio is simply the number of decibels the measured air conditioner noise level is above (or in excess of) the ambient background sound level. Because the measured air conditioner noise levels include the effect of the ambient background noise, this ratio should never be less than 0 dB except for the influence of small fluctuations in the background noise levels.

The mean value of signal/noise ratios at the source shown in Figure 7 was 10.8 dB(A). Thus, most source level measurements were not influenced by the existing background noise levels. In only a very small number of cases did the measured source levels approach the levels of the background noise.

For the other locations, the distribution of signal/noise ratios all include a pronounced peak at 0 dB(A). This probably indicates that a number of air conditioner noise levels were incorrect and actually reflected the level of the background noise. The situation gradually worsened in moving from the property-line to the facade and then to the patio. The mean signal/noise ratio at the property-line was 6.6 dB(A), at the facade was 4.7 dB(A), and at the patio was 2.3 dB(A).

Figure 7. Distribution of A-weighted signal/noise ratios for source position air conditioner noise measurements.

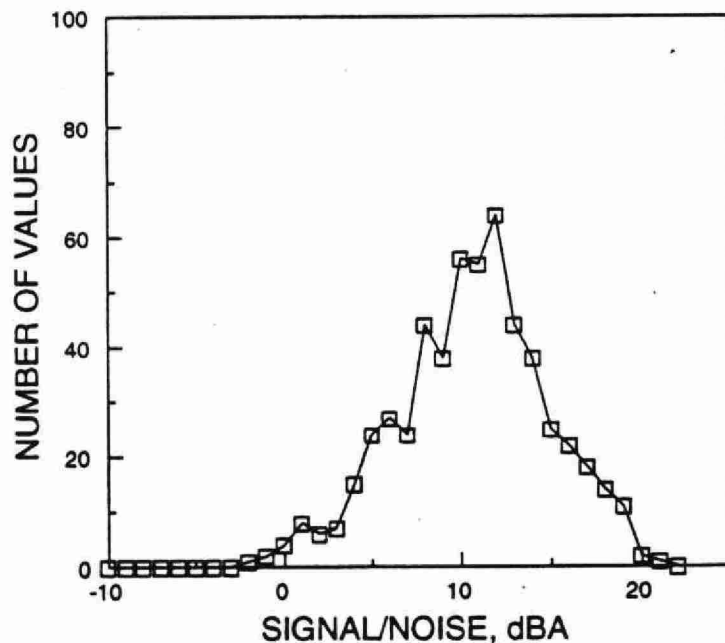


Figure 8. Distribution of A-weighted signal/noise ratios for property line air conditioner noise measurements.

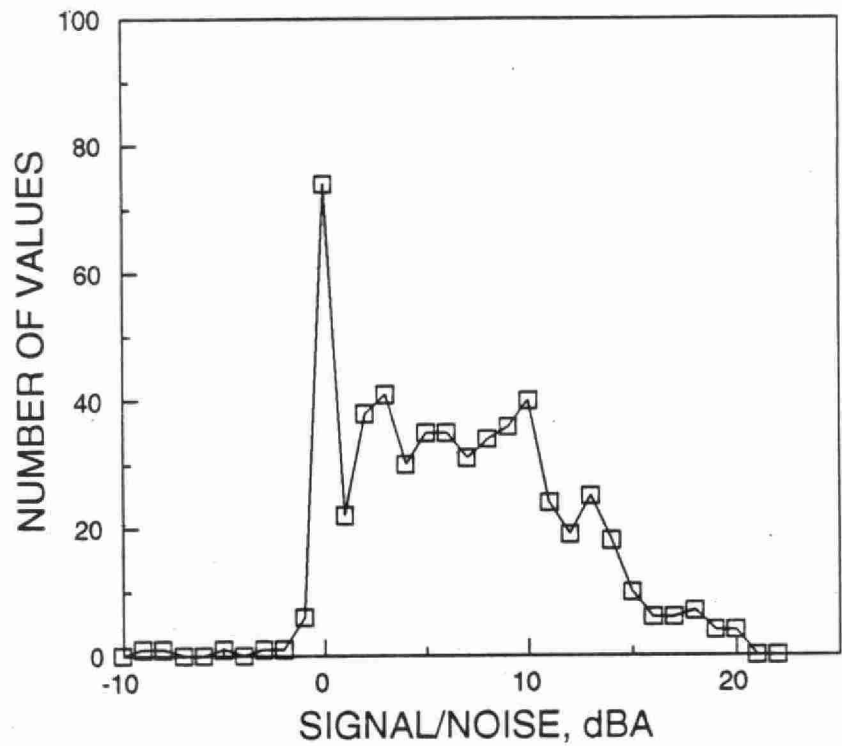


Figure 9. Distribution of A-weighted signal/noise ratios for facade position air conditioner noise measurements.

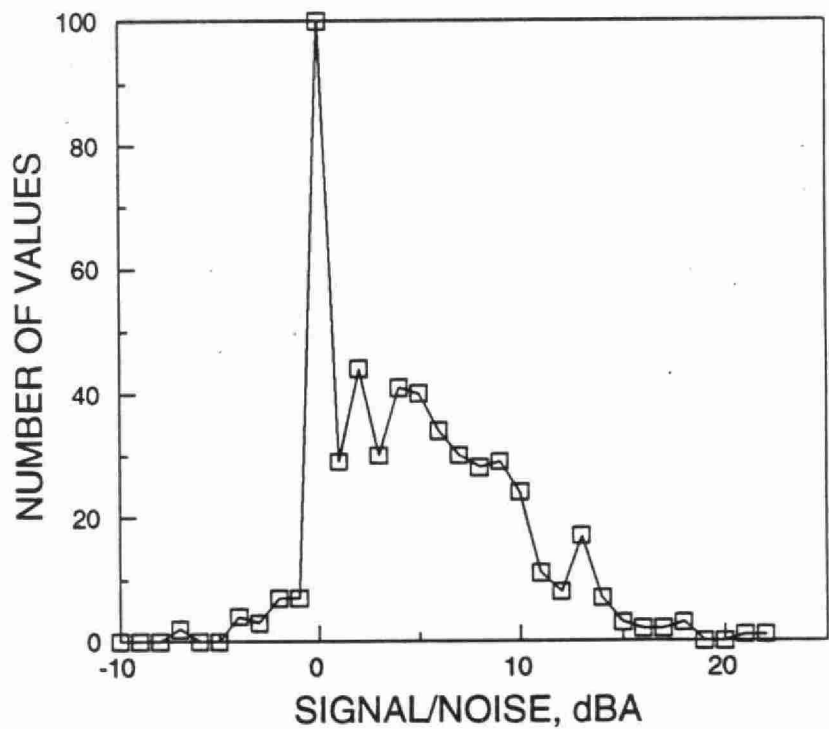
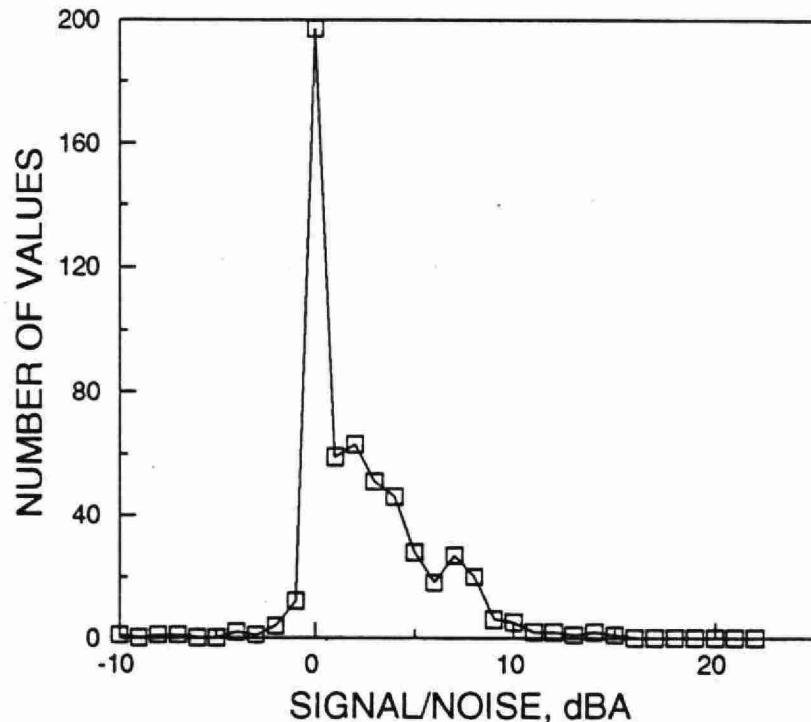


Figure 10. Distribution of A-weighted signal/noise ratios for patio air conditioner noise measurements.



One can correct the measured air conditioner noise levels by subtracting the measured background noise levels. This can only be reliably achieved when the air conditioner noise levels are significantly greater than the measured background levels, which was not true for all measurements.

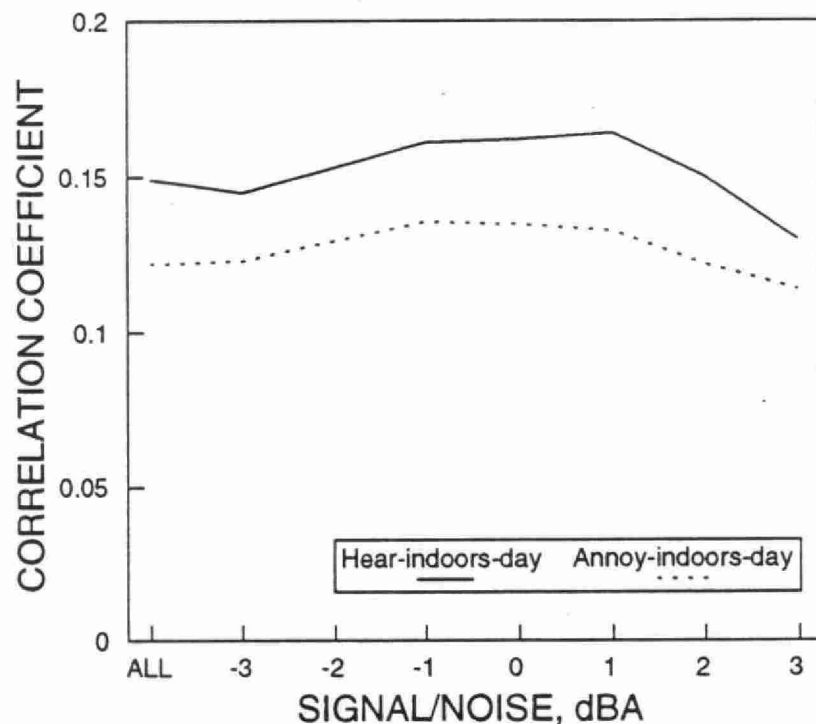
Excluding cases where the signal/noise ratios are very low should improve the correlations between noise measurements and subjective responses because for these cases the air conditioner noise levels do not accurately represent the actual air conditioner noise. To do this, one must decide which signal/noise ratio is to be used as a cut-off point to exclude data so that correlations between noise measures and subjective responses will be most improved. Accordingly, a range of cut-off signal/noise ratios were tested for the data from four measurement positions.

Signal/noise ratios at the source were first considered as criteria for excluding data. Signal/noise ratios of between 3 and 12 dB(A) were tried as cut-offs for excluding data. For each selection of data, all eight responses concerning air conditioner noise, as well as the composite scale "Hear" and "Annoy", were correlated with the various measured noise levels. Correlation coefficients tended to improve as lower signal/noise ratio data were excluded up

to signal/noise ratios just less than 9.0 dB(A). The improvement in correlation coefficients was small and the optimum case, excluding all data with signal/noise ratios at the source of less than 9.0 dB(A), eliminated almost half of the data.

Excluding data based on the signal/noise ratio at the property-line measurement position was next tried. Again, small improvements in correlation coefficients were obtained as the lower signal/noise ratio cases were excluded. Correlation coefficients generally exhibited a broad maximum for property-line signal/noise ratios of between 0 and +1.0 dB(A). Figure 11 illustrates the variation of correlation coefficients for two responses as the property-line signal/noise ratio cut-off was varied. These two responses were the reported frequency of hearing and being annoyed by air conditioner noise for subjects indoors during the day-time. The improvements for these and other responses were all quite small and in no case did insignificant correlations become significant.

Figure 11. Variation of correlation coefficients between property line noise levels and day-time indoor responses for varied cut-off of data based on signal/noise ratio.



When signal/noise ratios at the facade measurement position were used to select data, correlation coefficients were generally most improved for about a +2.0 dB(A) signal/noise ratio cut-off. However, most responses were still not significantly related to measured facade noise levels. The tests using signal/noise ratios at the patio



measurement position were less successful and no responses were found to significantly correlate with measured patio noise levels.

The benefits of excluding data based on signal/noise ratios of the related noise measurements were of limited value because the improvements in correlation coefficients were quite small and the process greatly reduced the number of subjects used in the analyses.

### 5.3 Signal/Noise Ratio as a Better Predictor

Some earlier results had suggested that signal/noise ratios and not noise levels were the better predictors of subjective responses. To test this idea, multiple linear regression analyses were performed regressing response scores onto linear combinations of each noise measure and the background noise level. For background noise and noise measured at the property-line, all eight responses concerning hearing or being annoyed by air conditioner noise were significantly related to the combined noise measures. For noise measurements at the facade, seven of the eight responses were significantly related to both noise measures. For noise measurements at the patio, responses were only related to background noise measures and only for five of the eight responses.

The measured environmental noise  $L_{eq}$  values were also tested to determine whether they might be a better indicator of ambient noise than the measured background noise levels with the air conditioner unit turned off. For the two night-time indoor responses, combinations of the property-line air conditioner noise levels and the night-time  $L_{eq}$  value were significant predictors. However, combinations of air conditioner noise levels and the background levels with the units turned off were always better predictors of responses.

Because of the success of combinations of property-line air conditioner noise levels and background noise levels, the signal/noise ratio at the property-line was created as a new objective predictor measure. Correlations between the eight principal air conditioner noise responses and this new measure are compared to correlations with the property-line noise levels in Table 4. Also shown are the results of correlations with the square and the cube of the property-line signal/noise ratios. In all cases the correlations with the signal/noise ratios were larger than with the property-line noise levels. Most often correlations with the square or the cube of the signal/noise ratios were a little stronger.



Table 4. Comparison of correlations of responses to air conditioner noise and property line noise levels, and property line signal/noise ratios. (ns = non-significant correlation)

| Noise Measure<br>dB(A)     | Indoors |       |            |            | Outdoors |            |            |       |
|----------------------------|---------|-------|------------|------------|----------|------------|------------|-------|
|                            | Day     |       | Night      |            | Day      |            | Night      |       |
|                            | Hear    | Annoy | Hear       | Annoy      | Hear     | Annoy      | Hear       | Annoy |
| Property line level        | .149    | .124  | .061<br>ns | .070<br>ns | .140     | .116<br>ns | .072<br>ns | .070  |
| Signal/noise ratio         | .185    | .169  | .123       | .135       | .195     | .183       | .123       | .38   |
| Signal/noise ratio squared | .190    | .178  | .140       | .154       | .178     | .193       | .118       | .144  |
| Signal/noise ratio cubed   | .188    | .180  | .149       | .163       | .160     | .191       | .106       | .140  |

The signal/noise ratio was always a better predictor of adverse responses to air conditioner noise. This may at least be partly due to minimizing the influence of cases where air conditioner noise levels were similar to background noise levels. It may also indicate that the signal/noise ratio is the more fundamentally correct predictor of adverse responses to air conditioner noise.

The best fit regression lines for each response versus the cube of the property-line signal/noise ratio were plotted and are shown in Figures 12 to 15. Figure 12 is for indoor responses in the day-time, and Figure 13 is for indoor responses at night. Figure 14 is for outdoor responses in the day-time, and Figure 15 is for outdoor responses at night. In all cases, the curves show almost no influence of signal/noise ratio below signal/noise ratios values of +5.0 dB(A). Between +5 and +10.0 dB(A), mean responses begin to increase with increasing signal/noise ratio. In all cases subjects seem to report hearing air conditioner noise more often than being annoyed by it.

All four figures suggest that adverse responses to air conditioner noise are not related to the air conditioner noise level below a signal/noise ratio of +5 dB(A). The quietest sites had background noise levels of approximately 45 dB(A). Thus, at these quietest sites there would be no detectable increase in adverse responses to air conditioner noise below 50 dB(A). Even at these very quiet sites, mean annoyance would increase only slightly for air conditioner noise levels of no more than approximately 55 dB(A).

Figure 12. Best fit regression lines for indoor day-time responses versus property line signal/noise ratio.

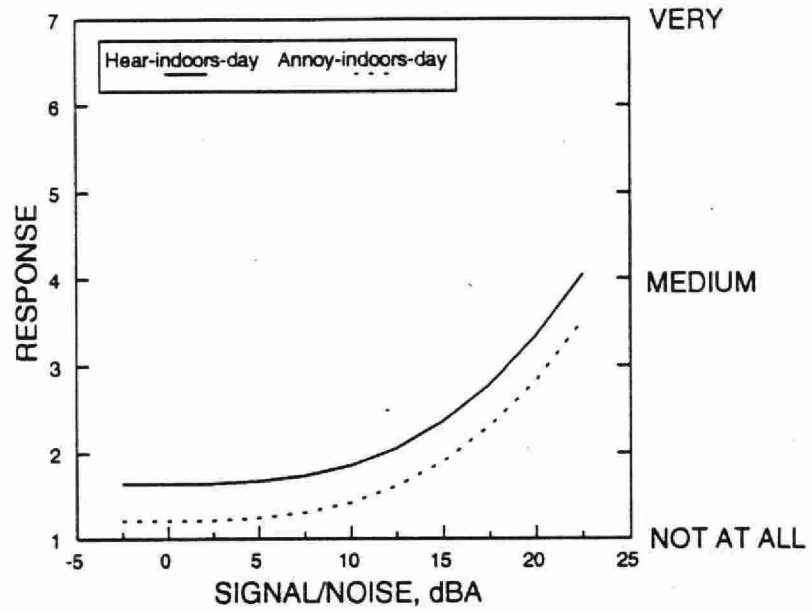


Figure 13. Best fit regression lines for indoor night-time responses versus property line signal/noise ratio.

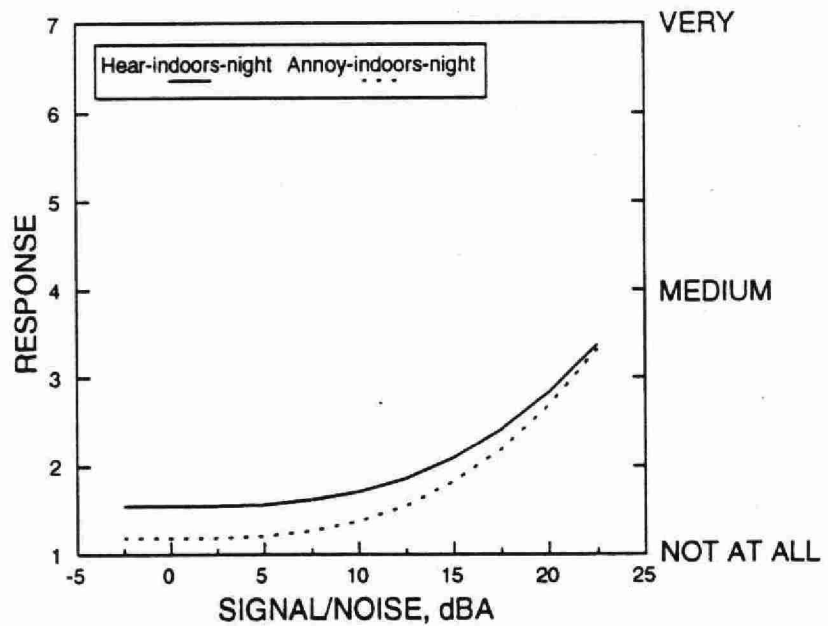


Figure 14. Best fit regression lines for outdoor day-time responses versus property line signal/noise ratio.

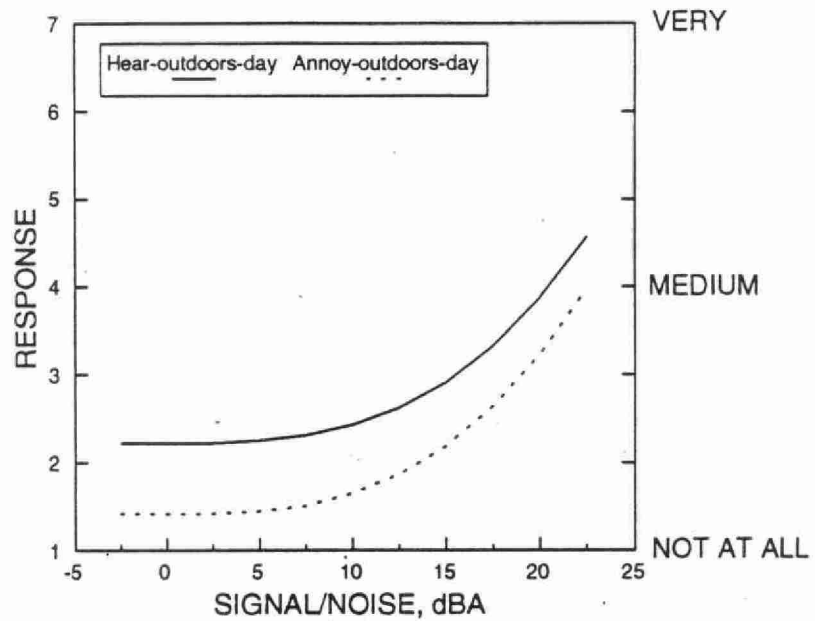
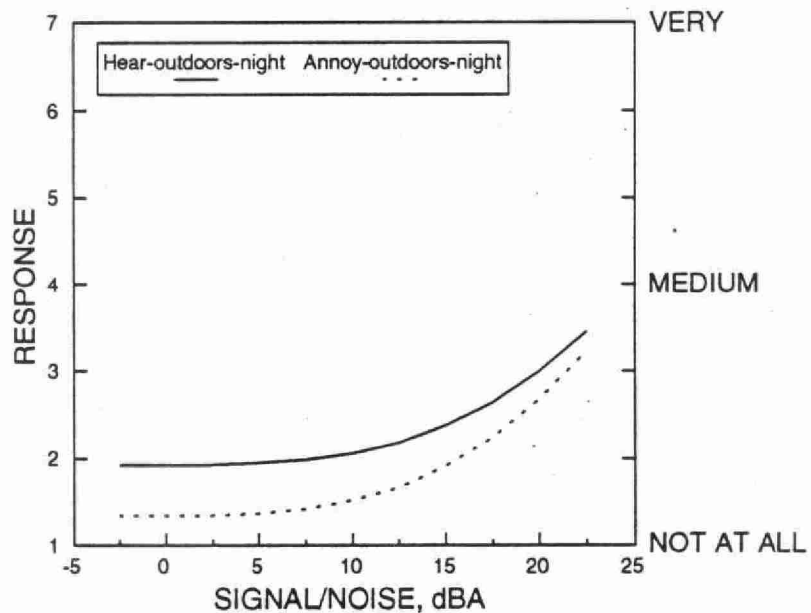


Figure 15. Best fit regression lines for outdoor night-time responses versus property line signal/noise ratio.



One must be cautious in interpreting these mean trend regression lines because they look deceptively precise. The standard deviations of the actual responses about these best fit lines ranged between 1.5 and 1.8 response scale points. Thus, at the lowest noise levels some subjects were as annoyed as others were at the highest noise levels. Of course, on average the trend is for annoyance to increase with signal/noise ratio above a threshold value of between +5 and +10 dB(A).

## 6. Individual Data and Subject Selection Variables

The experimental design for the survey was planned so that the influence of owning an air conditioner and of the ambient noise levels could be investigated. Subjects were selected so that they were equally distributed among four different groups. These four groups were the four combinations of high and low ambient noise levels with owners and non-owners of air conditioners.

### 6.1 Success of Subject Selection Procedure

Measured 24-hour  $L_{eq}$  values varied from 53 to 69 dB(A), with a mean of approximately 60 dB(A) and a standard deviation of 3.2 dB(A) (see Table 1). Thus, it was possible to split subjects at an  $L_{eq24}$  of 60 and obtain two approximately equal groups representing higher and lower ambient noise levels.

The distribution of the subjects between owners and non-owners was not as successfully achieved. Subjects were chosen on the basis of whether a central air conditioning system appeared to be present. Of the 599 interviewed subjects, 331 (55.3%) had central air conditioners. Unfortunately, 129 subjects had window air conditioners. Table 5 describes the distribution of subjects among the four groups. In total, 445 subjects (74.3%) had at least one type of air conditioner and only 151 (25.2%) had no air conditioner.

This uneven distribution of owners and non-owners seriously compromises the experimental design. The much smaller number of non-owners made it more difficult to obtain statistically significant results for this group.

Table 5. Distribution of subjects among four groups of ambient noise level and ownership of an air conditioner

|                 | Ownership |           | Total |
|-----------------|-----------|-----------|-------|
|                 | Owner     | Non-owner |       |
| Low $L_{eq24}$  | 243       | 85        | 328   |
| High $L_{eq24}$ | 202       | 66        | 268   |
| Total           | 445       | 151       | 596   |

### 6.2 Analysis of Variance Results

The influence of ownership and ambient noise levels was first investigated using two way analyses of variance. The data were divided into four groups as described in Table 5 so that there were two levels of each of the two independent variables, ownership and ambient noise level. The high and low ambient noise groups were first based on the  $L_{eq24}$  values. Subsequently, high and low noise groups were also created by using day- and night-

time  $L_{eq}$  values. All eight responses concerning hearing and being annoyed by air conditioner noise were used as dependent variables.

Using  $L_{eq24}$  values to create high and low ambient noise groups led to significant main effects of ownership on all four annoyance responses such that non-owners tended to be more annoyed. There was also a significant main effect of ambient noise level ( $L_{eq24}$ ) on responses concerning how often air conditioner noise was heard while outside in the day-time. For several other responses, a main effect was almost significant ( $p < .05$ ). There were no significant interaction effects.

When high and low ambient noise level groups were created using either day-time or night-time  $L_{eq}$  values, the significant main effects of ownership on annoyance responses were always observed. When the night-time  $L_{eq}$  values were used, there was also a main effect of noise level ( $L_{eqN}$ ) on indoor night-time responses. When day-time  $L_{eq}$  values were used, there was a significant interaction effect such that there was a greater effect of ambient noise level for subjects that did not own air conditioners.

Thus, there was a consistent effect for non-owners of air conditioners to be more annoyed by the noise of their neighbours' air conditioner. However, being able to hear one's neighbours' air conditioner was understandably not influenced by owning a unit. In some cases, the measured ambient noise also had some effect on responses.

### 6.3 Influence of Air Conditioner Ownership

Further analyses were carried out to attempt to quantify the influence of owning an air conditioner. The data were first divided into two groups according to whether subjects owned an air conditioner. For each group, regression analyses were carried out for the eight air conditioner noise responses versus measured air conditioner noise levels. For the smaller non-owner group, significant relationships were not found. Thus, it was not possible to compare owners and non-owners as a function of air conditioner noise level.

As a simpler form of analysis, the mean response of each group (owners/non-owners) was calculated and the differences were tested using analysis of variance. Significant differences were usually found for annoyance responses, and these annoyance differences were related to equivalent differences in air conditioner noise level. These data are given in Table 6. The mean values for

each ownership condition are given for each of the four annoyance responses. The differences between the means are also given, as well as the significance of these differences. For comparison, property-line air conditioner noise levels and 24-hour  $L_{eq}$  values are also given.

Table 6. Mean differences between annoyance responses of owners and non-owners. Bracketed values are not significant ( $p < .05$ ).

|                           | <u>Indoors</u> |                | <u>Outdoors</u> |                | Property<br>line level<br>(dB(A)) | $L_{eq24}$<br>(dB(A)) |
|---------------------------|----------------|----------------|-----------------|----------------|-----------------------------------|-----------------------|
|                           | Day<br>Annoy   | Night<br>Annoy | Day<br>Annoy    | Night<br>Annoy |                                   |                       |
| Mean value<br>owners      | 1.30           | 1.23           | 1.53            | 1.39           | 59.8                              | 60.2                  |
| Mean value<br>non-owners  | 1.62           | 1.68           | 1.82            | 1.75           | 59.3                              | 59.6                  |
| Difference<br>of means    | 0.32           | 0.45           | 0.29            | 0.36           | -0.5                              | -0.6                  |
| Significance<br>less than | .035           | .004           | (.076)          | .035           | (.212)                            | (.084)                |

Three of the annoyance differences are statistically significant ( $p < .05$ ), but the noise level differences are too small to be significant. Thus, both owners and non-owners were on average exposed to the same air conditioner and ambient noise levels. In spite of the noise exposures being equal, annoyance responses were not. Non-owners were in all cases more annoyed by air conditioner noise than were owners. Mean differences in annoyance responses varied from 0.32 to 0.45 annoyance scale points.

The mean differences in annoyance responses were converted to equivalent air conditioner noise level differences from regressions of annoyance responses against property-line air conditioner noise levels for the complete data set. (The complete data set was used so that statistically significant results could be obtained.) The slopes of these regression lines varied between 0.45 and 0.60 annoyance scale points per 10 dB(A). Thus, each annoyance difference could be converted to an equivalent air conditioner noise level difference. The average of these equivalent noise level differences was 7.3 dB(A).

On average, owning an air conditioner made subjects 7.3 dB(A) more tolerant of their neighbours' air conditioner. This may have simply been that with their own air conditioner operating it was more difficult to hear their neighbours' unit. One could conclude from this that maximum permissible air conditioner noise levels at sites where all homes have air conditioners could be 7 dB(A)

higher than for sites of mixed air conditioner ownership. The mean level of annoyance at both types of sites would be expected to be similar. While this might on average be acceptable, there will always be some residents who are more highly annoyed even though they do own an air conditioner.

#### 6.4 Influence of Ambient Noise Conditions

To attempt to quantify the influence of ambient noise levels on the adverse effects of air conditioner noise, regression analyses were performed for response scores versus property-line air conditioner noise levels. These regression analyses were performed separately for the high and low noise groups based on an  $L_{eq24}$  split. Not all of the responses were significantly related to property-line noise levels. Figures 16 and 17 show regression lines that are representative of these results.

Figure 16. Best fit regression lines for how often subjects hear neighbours' air conditioner while outdoors during the day-time for high and low ambient noise groups.

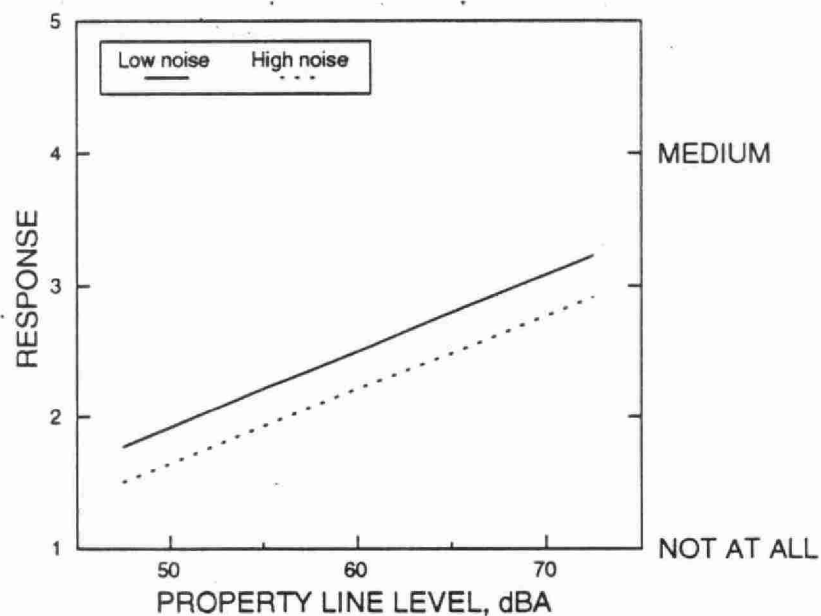


Figure 16 plots the mean regression lines for the responses concerning how often air conditioner noise was heard while the subjects were outside in the day-time. From this Figure, it is seen that subjects at low ambient noise sites heard air conditioner noise more often; this difference was essentially independent of the air conditioner noise level. The horizontal difference between the two almost parallel regression lines is approximately 5 dB(A). Thus, at low ambient noise sites, subjects would hear 60 dB(A) air conditioner noise approximately as often as subjects at high noise sites would report hearing 65 dB(A) air conditioner noise.



This difference seems to be directly related to the different masking effect of the ambient noise at high and low noise sites. The average  $L_{eq24}$  was 57.4 dB(A) at the low noise sites and 62.6 dB(A) at the high noise sites. The difference in ambient noise levels, as measured by  $L_{eq24}$  values, was approximately 5 dB(A). Thus, at high noise sites where the ambient noise is on average 5 dB(A) louder, it requires 5 dB(A) more air conditioner noise for high noise subjects to hear it as often as low noise subjects. When the same subjective response scores were regressed against the property-line signal/noise ratios, the resulting two regression lines were very similar, indicating no differences between low and high ambient noise sites. This test suggests that the fundamental predictor variable is the signal/noise ratio, and not the measured level.

Figure 17. Best fit regression lines for outdoor day-time annoyance of neighbours' air conditioner for high and low ambient noise groups.

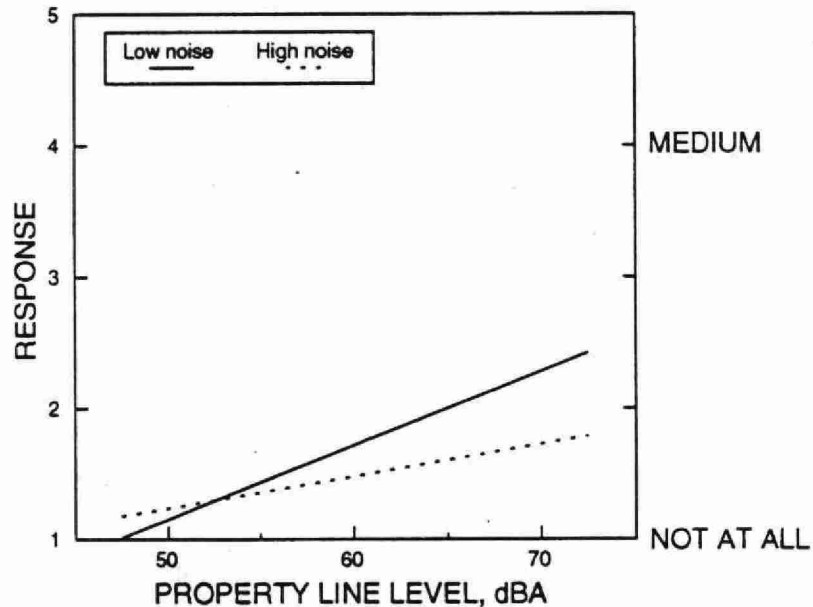


Figure 17 compares regression lines for annoyance responses for the same situation as in Figure 16, i.e. for subjects outdoors during the-day-time and for both low and high ambient noise sites. In this case, annoyance responses were very similar at low property-line air conditioner noise levels, but diverged for higher air conditioner noise levels. Thus, for very low air conditioner noise levels where subjects probably would have difficulty hearing the air conditioner noise, mean annoyance responses were very similar and approximately equal to 1.0, indicating that no annoyance occurred. At higher noise levels, low ambient noise subjects were more annoyed by the same air conditioner

noise level. When the same annoyance responses were regressed against the property-line signal/noise ratios, the two regression lines were very similar, indicating no differences between high and low ambient noise subjects. Once again, the effect of ambient noise level seemed to be more fundamentally a signal/noise ratio effect.

The ambient noise at a site does have some influence on adverse response to air conditioner noise. At low ambient noise sites, subjects hear their neighbours' air conditioner more often and are more annoyed by their neighbours' air conditioner noise, particularly so at higher air conditioner noise levels. The magnitude of these differences seems to be directly related to the corresponding differences in ambient noise levels, and the differences do not occur when signal/noise ratios are used to predict responses. Thus, the effect of ambient noise, and the differences between low and high noise sites, seems to simply be a signal/noise effect. Adverse responses to air conditioner noise are more directly related to the resulting signal/noise ratio than to the absolute noise levels.

## 7. Individual Data and Non-Noise Predictors

To examine the combined effect of noise and non-noise predictors, stepwise multiple regression analyses were performed regressing responses to air conditioner noise onto combinations of predictor variables. In the first series of regression analyses, all of the measured noise levels were included as possible predictor variables. In a second series of analyses, only the property-line signal/noise ratio was included as a possible noise predictor variable. The non-noise predictors included all the socio-economic variables describing each subject.

Table 7(a) summarizes the results of the first series of regression analyses. For each air conditioner noise response, the order of entry of the predictor variables into the stepwise regression analyses is given. The sign in front of this number indicates whether the coefficient of this term in the regression equation was negative or positive. For the first response variable, concerning hearing air conditioner noise while indoors in the day-time, the source level was the first term in the equation and it had a positive coefficient. The second term was the measured background noise levels and it had a negative coefficient. Thus, for increased source levels, subjects reported hearing air conditioner noise more often, but for increased background noise they reported hearing air conditioner noise less often. The question concerning whether they kept windows open was scored such that the observed negative coefficient indicated that subjects who

kept windows open heard their neighbours' air conditioner more often. At the bottom of this table, the final multiple correlation coefficient is given.

Table 7(a) also indicates that the property-line air conditioner noise level and the background noise level were most frequently included in these regression equations. For night-time responses, the night-time  $L_{eq}$  values were also included for three out of the four night-time responses.

For the indoor responses, the only non-noise predictor that was included was the question concerning whether windows were kept open. For outdoor responses, education, income and age were also included as well as in one case the number of young people at each home. The results were such that more educated respondents, higher income respondents, and homes with more young people responded more strongly to air conditioner noise. For one response, older subjects were more annoyed. However, this may be due to the fact that subjects' ages were correlated with background noise levels. On another response, subjects who owned a central air conditioner heard their neighbours' air conditioner less often.

The last two columns of Table 7(a) are the results for the combined "Hear" and "Annoy" scales. (These were created by adding the four annoyance responses to create the "Annoy" scale, and the four responses concerning how often air conditioner noise was heard, to create the scale "Hear".) For these composite scale results, most of the non-noise predictors do not enter into the equations. Only the having windows open variable influences "Annoy" responses. Summing responses for these composite scales averages out the differences between day and night as well as indoors and outdoors, causing the number of non-noise predictors to be much reduced.

When the property-line signal/noise ratio is the only allowed noise predictor variable, the pattern of selected non-noise predictors shown in Table 7(b) is a little changed. Owning a central air conditioner, as well as whether windows were kept open, influenced indoor responses. Also in this case, significant results were obtained for indoor day-time annoyance. For outdoor responses, education, age, owning an air conditioner, or owning a central air conditioner were significant predictors. The number of adults and the number of young people at each home each entered into one of these regression equations. For the composite scales "Hear"

and "Annoy", only education and owning a central air conditioner were significant non-noise predictors.

From the results shown in Table 7(a) and 7(b), it is seen that noise measures are not always the most important predictors of the responses to air conditioner noise. This again suggests that air conditioner noise levels are low enough that they do not always disturb respondents, and that in some cases measured air conditioner noise levels do not accurately reflect the noise produced by the air conditioner. As the disturbing air conditioner noise is increasingly masked by the background noise, one would expect responses to be more influenced by non-noise factors as was observed in these results.

Table 7(a). Order of entry of significant predictor variables into multiple linear regression analyses of noise and non-noise predictors for hearing of, and annoyance to, air conditioner noise.

| Predictor Variable               | Indoors |       |       |       | Outdoors |       |       |       | Combined |       |
|----------------------------------|---------|-------|-------|-------|----------|-------|-------|-------|----------|-------|
|                                  | Day     |       | Night |       | Day      |       | Night |       |          |       |
|                                  | Hear    | Annoy | Hear  | Annoy | Hear     | Annoy | Hear  | Annoy | Hear     | Annoy |
| Source level, dB(A)              | +1      |       |       |       |          |       |       |       |          |       |
| Property line level, dB(A)       |         |       |       |       | +3       | +3    |       |       | +2       | +3    |
| Background level, dB(A)          | -2      |       |       |       |          |       | -2    | -2    | -1       | -1    |
| Night-time $L_{eq}$ , dB(A)      |         |       |       |       |          |       | -2    |       |          |       |
| Patio level, dB(A)               |         |       |       |       | -4       |       |       |       |          |       |
| Windows open                     | -3      |       | -2 -2 |       | -4       |       |       |       | -2       |       |
| Age                              |         |       |       |       |          |       |       |       | -1       |       |
| Education                        |         |       |       |       | +1       | +1    |       |       |          |       |
| Income                           |         |       |       |       |          |       |       |       | +3       |       |
| Own air conditioner              |         |       |       |       | -2       |       |       |       |          |       |
| Own central air conditioner      |         |       |       |       |          |       |       |       |          |       |
| No. adults                       |         |       |       |       |          |       |       |       |          |       |
| No young people                  |         |       |       |       |          |       |       |       | +1       |       |
| Multiple correlation coefficient | .225    | ns    | .163  | .189  | .291     | .233  | .192  | .177  | .182     | .198  |

Table 7(b). Order of entry of significant predictor variables into multiple linear regression analyses of property line signal/noise ratio and non-noise predictors for hearing of, and annoyance to, air conditioner noise.

| Predictor<br>Variable                         | <u>Indoors</u> |       |              |       | <u>Outdoors</u> |       |              |       | Combined |       |
|-----------------------------------------------|----------------|-------|--------------|-------|-----------------|-------|--------------|-------|----------|-------|
|                                               | <u>Day</u>     |       | <u>Night</u> |       | <u>Day</u>      |       | <u>Night</u> |       |          |       |
|                                               | Hear           | Annoy | Hear         | Annoy | Hear            | Annoy | Hear         | Annoy | Hear     | Annoy |
|                                               | Hear           | Annoy | Hear         | Annoy | Hear            | Annoy | Hear         | Annoy | Hear     | Annoy |
| Property line<br>signal/noise<br>ratio, dB(A) | +1             | +1    | +1           | +2    | +1              | +2    |              | +2    | +1       | +1    |
| Windows open                                  | -2             |       | -2           |       |                 |       |              |       |          |       |
| Age                                           |                |       |              |       |                 |       |              | -1    |          |       |
| Education                                     |                |       |              |       | +2              | +1    | +1           |       | +2       |       |
| Income                                        |                |       |              |       |                 |       |              |       |          |       |
| Own air<br>conditioner                        |                |       |              |       | -3              |       | -2           |       |          |       |
| Own central air<br>conditioner                |                | +2    |              | +1    |                 |       |              | +3    | +2       |       |
| No. adults                                    |                |       |              |       |                 |       |              |       |          |       |
| No young<br>people                            |                |       |              |       |                 | -3    | +3           |       |          |       |
| Multiple<br>correlation<br>coefficient        | .185           | .164  | .146         | .165  | .272            | .226  | .200         | .187  | .198     | .191  |

## 8. Grouped Data

### 8.1 Simple Relations with Noise Level Predictors

By aggregating scores for groups of respondents, one can calculate the percentage of each group that reports hearing their neighbours' air conditioner or being annoyed by it. Various schemes for grouping the data were tried, but the most successful consisted of grouping subjects responses for eight property-line air conditioner noise level groups. Each group included a 3 dB(A) wide range of property-line air conditioner noise levels. The lowest and highest groups were open-ended. From each of the eight groups, the percentage of subjects scoring greater than one on each of the air conditioner noise response scales was calculated. These percentage values were then plotted versus the group mean noise levels and subjected to various statistical analyses.

Percentage responses were correlated with the group mean property-line noise levels, the group mean property-line signal/noise ratios, as well as the square and the cube of each of these quantities. Responses concerning the percentage of subjects hearing the neighbours' air conditioner were most strongly correlated with the linear noise measures. The percentage of subjects annoyed by the noise of their neighbours' air conditioner were more strongly correlated with the cube of the noise measures.

Figure 18 shows the percentage of subjects hearing their neighbours' air conditioner versus mean property-line noise level. The actual data points as well as the best fit linear regression lines are both shown. These results quite logically show that subjects heard their neighbours' air conditioner more often when they were outside. For both indoor and outdoor situations, subjects heard their neighbours' air conditioner more often during the day-time. While indoors, the percentage of subjects hearing their neighbours' air conditioner varied from a low of about 15% to a high of over 40%. When subjects were outside, the percentages were higher. They varied from approximately 30% to as high as 70%. Thus, significant numbers of people do hear their neighbours' air conditioner.

Figure 18. Percentage of subjects hearing air conditioner noise for day- and night-time while both indoors and outdoors versus property line air conditioner noise level.

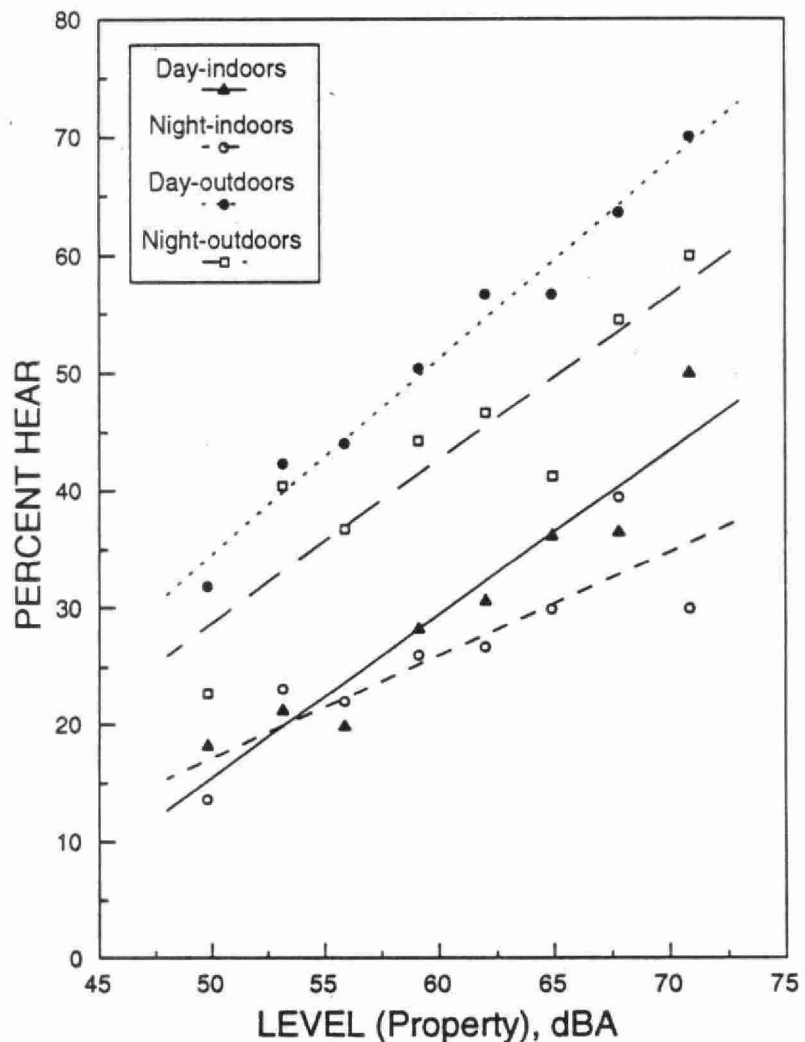
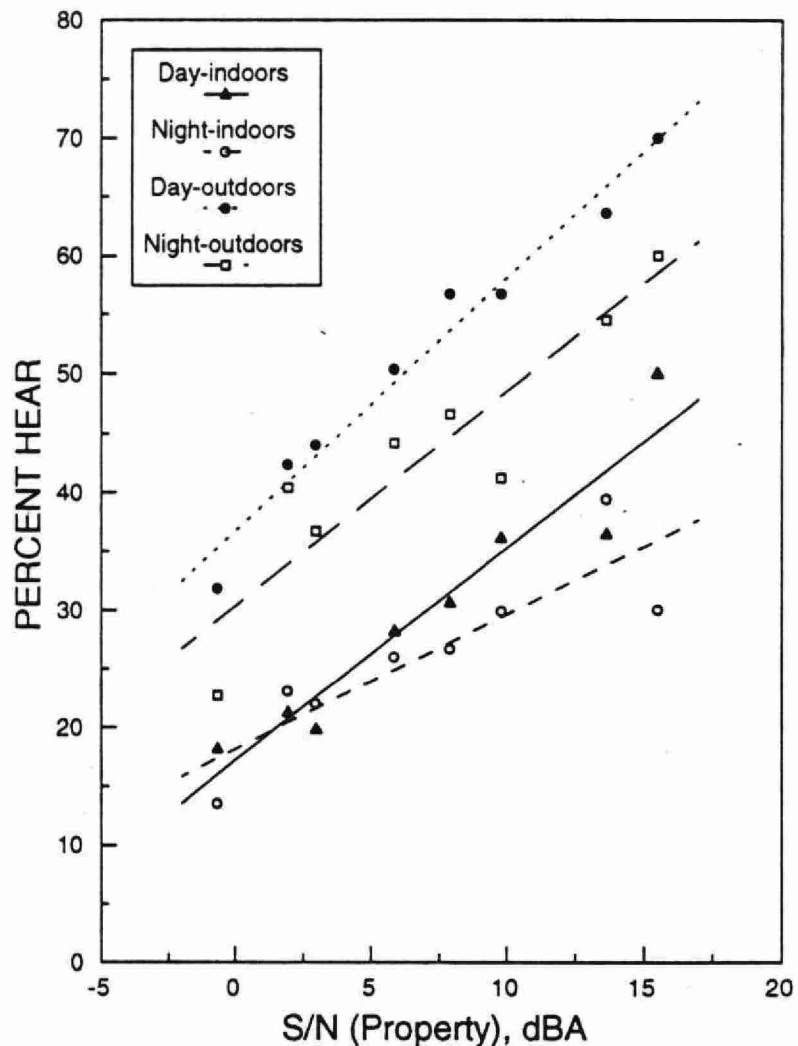


Figure 19 plots the same percentage responses versus the mean property-line signal/noise ratio. The results are very similar to those of Figure 18 at least partly because the data were grouped by property-line noise level. For these groups, the signal/noise would not be independent of the mean levels. The regression equations corresponding to these lines on these two graphs are given in Table 8, along with the multiple regression coefficients.

Figure 19. Percentage of subjects hearing air conditioner noise for day- and night-time while both indoors and out doors versus property line air conditioner signal/noise ratio.

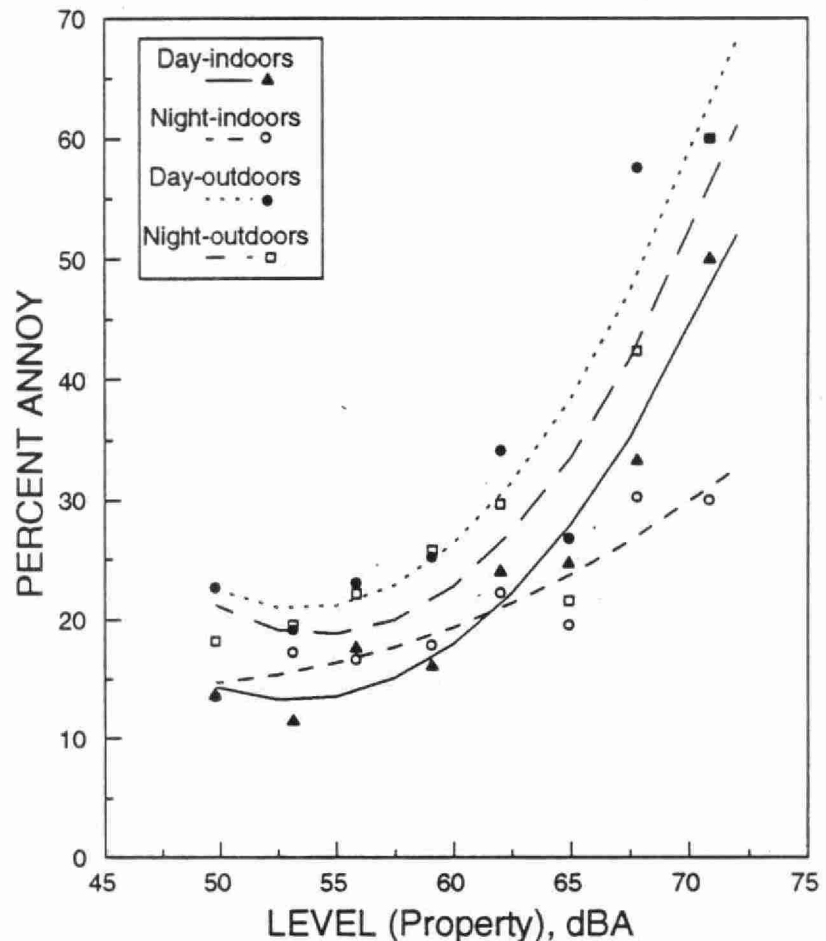


The percentages of subjects who were annoyed by the noise of their neighbours' air conditioner are plotted versus mean property-line noise levels in Figure 20. The equations of the best fit regression lines, shown in Table 8, include the cube of the mean measured noise levels. The curve of the regression lines at the lowest noise levels is of no practical significance and is simply due to the limitations of the curve fitting process with a



small number of data points. The differences among the four sets of data are similar, but smaller, than those in Figures 18 and 19 for the percentage of subjects hearing their neighbours' air conditioner. Subjects were more annoyed when outside, and when outdoors they were most annoyed during the day-time.

Figure 20. Percentage of subjects annoyed by conditioner noise for day- and night-time while both indoors and outdoors versus property line air conditioner noise level.



The same percentage of subjects annoyed by their neighbours' air conditioner noise are plotted versus the property-line signal/noise ratio in Figure 21. The pattern of results is very similar to the results of the previous figure. In both cases, annoyance seems to level off at a more or less constant residual value at low noise levels. It is only when the property-line noise level exceeds about 55 dB(A) or when the signal/noise ratio exceeds approximately +5 dB(A) that the percentage of annoyed subjects increases markedly with increasing noise level.

Figure 21. Percentage of subjects annoyed by air conditioner noise for day- and night-time while both indoors and outdoors versus property line air conditioner signal/noise ratio.

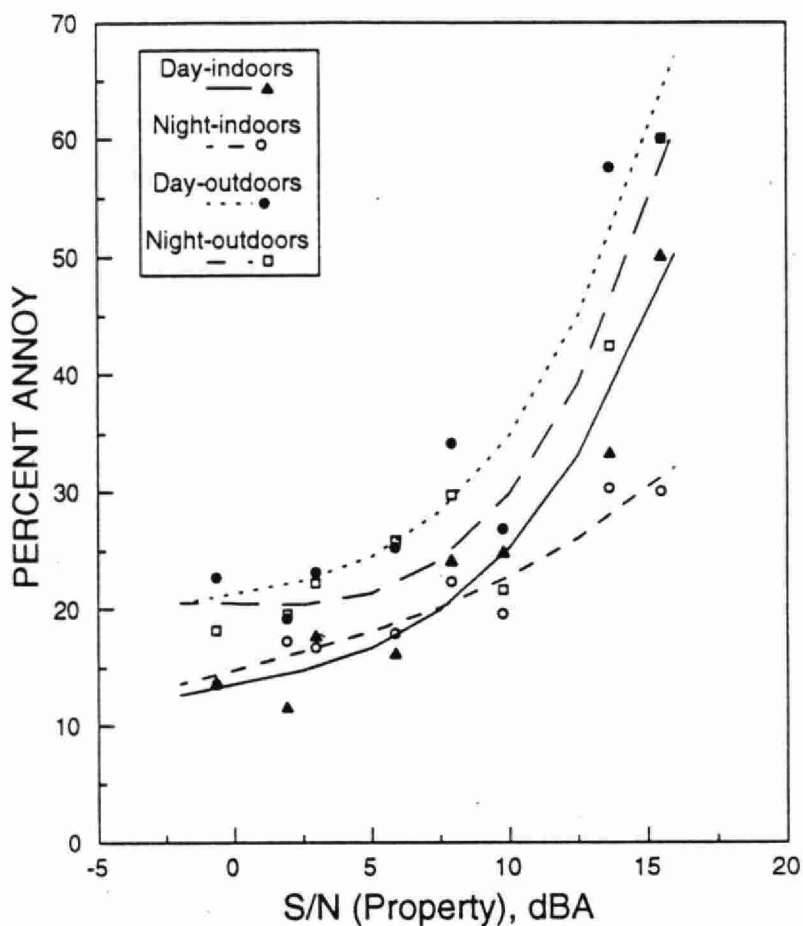


Table 8. Best fit regression equations from grouped data for percentage of subjects hearing neighbours air conditioner or annoyed by the neighbours' air conditioner noise versus property line noise level or signal/noise ratio.

| Percent hearing neighbours air conditioner versus dBAP<br>(A-weighted air conditioner noise level at the property line).       |                                                             |  | Correlation<br>coefficient |
|--------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|--|----------------------------|
| Indoors, day-time                                                                                                              | Percent = 1.396 dBAP - 54.35                                |  | .953                       |
| Indoors, night-time                                                                                                            | Percent = 0.881 dBAP - 26.92                                |  | .866                       |
| Outdoors, day-time                                                                                                             | Percent = 1.671 dBAP - 49.11                                |  | .988                       |
| Outdoors, night-time                                                                                                           | Percent = 1.394 dBAP - 41.00                                |  | .901                       |
| Percent hearing neighbours air conditioner versus SNAP (A-weighted signal/noise ratio at the property line).                   |                                                             |  |                            |
| Indoors, day-time                                                                                                              | Percent = 1.804 SNAP - 17.17                                |  | .957                       |
| Indoors, night-time                                                                                                            | Percent = 1.148 SNAP - 18.14                                |  | .876                       |
| Outdoors, day-time                                                                                                             | Percent = 2.146 SNAP - 36.62                                |  | .985                       |
| Outdoors, night-time                                                                                                           | Percent = 1.820 SNAP - 30.30                                |  | .914                       |
| Percent annoyed by neighbours air conditioner noise versus dBAP (A-weighted air conditioner noise level at the property line). |                                                             |  |                            |
| Indoors, day-time                                                                                                              | Percent = -5.218 dBAP + 0.000615 dBAP <sup>3</sup> + 198.22 |  | .979                       |
| Indoors, night-time                                                                                                            | Percent = -0.993 dBAP + 0.000160 dBAP <sup>3</sup> + 44.34  |  | .931                       |
| Outdoors, day-time                                                                                                             | Percent = -6.662 dBAP + 0.000775 dBAP <sup>3</sup> + 258.62 |  | .933                       |
| Outdoors, night-time                                                                                                           | Percent = -6.653 dBAP + 0.000751 dBAP <sup>3</sup> + 259.76 |  | .927                       |
| Percent annoyed by neighbours' air conditioner noise versus SNAP (A-weighted signal/noise ratio at the property line).         |                                                             |  |                            |
| Indoors, day-time                                                                                                              | Percent = 0.429 SNAP + 0.00727 SNAP <sup>3</sup> + 13.59    |  | .975                       |
| Indoors, night-time                                                                                                            | Percent = 0.607 SNAP - 0.00188 SNAP <sup>3</sup> + 14.77    |  | .957                       |
| Outdoors, day-time                                                                                                             | Percent = 0.375 SNAP - 0.00971 SNAP <sup>3</sup> + 21.28    |  | .960                       |
| Outdoors, night-time                                                                                                           | Percent = -0.092 SNAP - 0.01023 SNAP <sup>3</sup> + 20.45   |  | .958                       |

## 8.2 Influence of Subject Selection Variables

Attempts were made to find evidence of the effects of the main subject selection variables using the grouped data. Both the influence of owning an air conditioner and the site ambient noise levels were considered.

The influence of owning an air conditioner was examined in two different ways. First, new aggregate data files were created separately for owners and non-owners of air conditioners. For each separate set of grouped data, percentage responses were regressed onto noise levels and signal/noise ratios. Some of these results were statistically significant and tended to indicate that owners were a little less annoyed by their neighbours' air conditioner noise. The effects were very small and not always consistent.

The question of the influence of ownership was also considered by performing multiple linear regression analyses of the percentage scores on both a noise measure and the ownership variable. No clear effect of owning an air conditioner was obtained from these analyses.

The question of the influence of the ambient site noise was also considered by creating separate high and low ambient noise grouped data files. Regression analyses were performed for all percentage response scores, and the results compared for high and low ambient noise cases. Not all results were statistically significant and many produced regression lines that were very similar or overlapping for the high and low noise cases. Figures 22 and 23 present the most successful results. Figure 22 plots the percentage of subjects hearing their neighbours' air conditioner when they are outdoors in the day-time. A larger percentage of subjects at low ambient noise sites reported hearing their neighbours' air conditioner. A similar effect is seen in Figure 23 for the percentages of subjects hearing their neighbours' air conditioner while outdoors at night. Again, a larger percentage of subjects at low ambient noise sites reported hearing their neighbours' air conditioner. The horizontal difference between the two regression lines is approximately 8 dB(A) in Figure 22 and 6 dB(A) in Figure 23, or on average approximately 7 dB(A). Thus, from these data the influence of owning an air conditioner reduces one's sensitivity to hearing a neighbours' air conditioner by about 7 dB(A). This is similar to the result obtained for the individual subject data in section 6.3.

Figure 22. Best fit regression lines for the percentage of subjects hearing air conditioner noise while outdoors during the day-time versus property line air conditioner noise level.

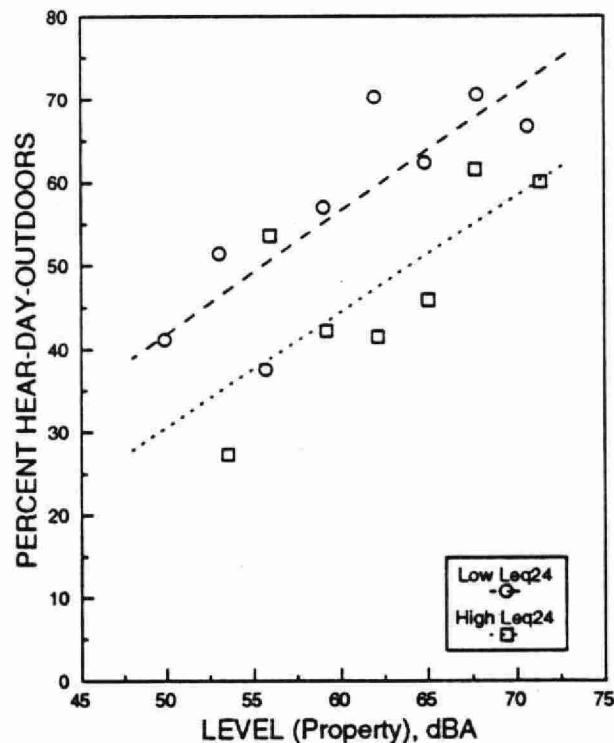
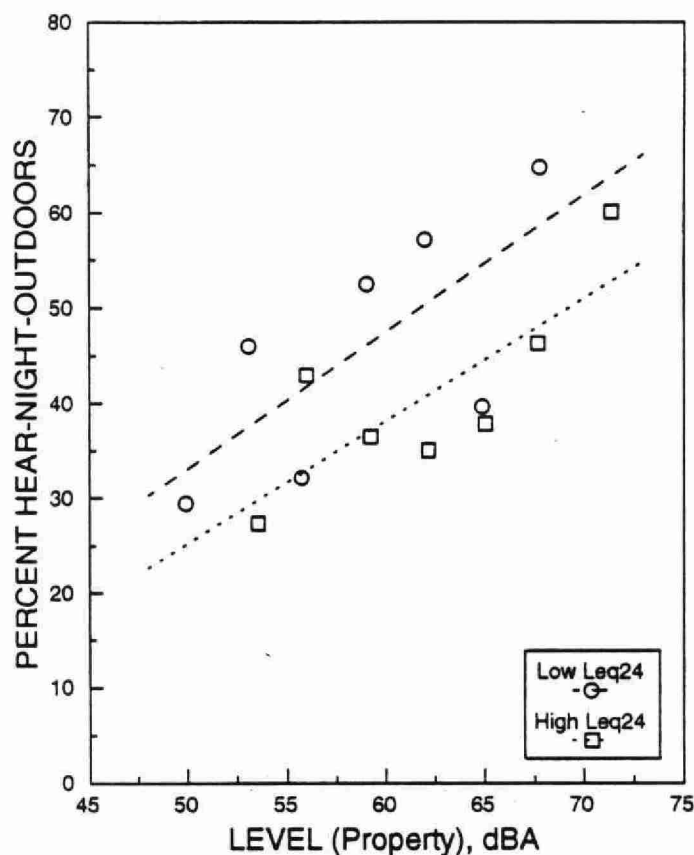


Figure 23. Best fit regression lines for the percentage of subjects hearing air conditioner noise while outdoors during the night-time versus property line air conditioner noise level.



The effect of ambient noise level was also investigated by creating grouped data based on 24-hour  $L_{eq}$  categories. Percentage scores were calculated for eight  $L_{eq}$  24 groups each including a 2 dB(A) range of  $L_{eq}$  24 values. Analysis of this grouped data generally did not produce useful statistically significant relationships.

### 8.3 Influence of Non-Noise Predictors

When subject responses are averaged together in groups, one would expect that the effect of individual differences would be reduced. Multiple regression analyses were performed regressing the group percentage scores onto combinations of noise and non-noise predictors. The property-line signal/noise ratio was used as the noise predictor as well as its square or its cube. A few non-noise variables were significant predictors, but the actual variables that were included in the regression equations varied when the noise predictor was varied. Generally, the results confirmed expectations in that non-noise predictors were not particularly important for the grouped data.

## 9. Comparisons with the ARI Noise Level Prediction Procedure

### 9.1 Predictions from Manufacturers' Ratings

The ARI A-weighted sound power ratings in bells were obtained by MOE for 125 of the units. From these sound power ratings, it is possible to predict air conditioner noise levels and to compare them with measurements at various points. These predictions were performed in accordance with the ARI Standard 275-84 procedure.

Predictions were first compared with measured source levels that were obtained from positions 6 feet (1.83 m) from the outdoor units. One can predict these source levels from the sound power ratings in bells using the following equation.

$$\text{Source level} = \text{BELS} \cdot 10 - 16.2 + 3.0 + \text{NES} \cdot 3 \quad (1)$$

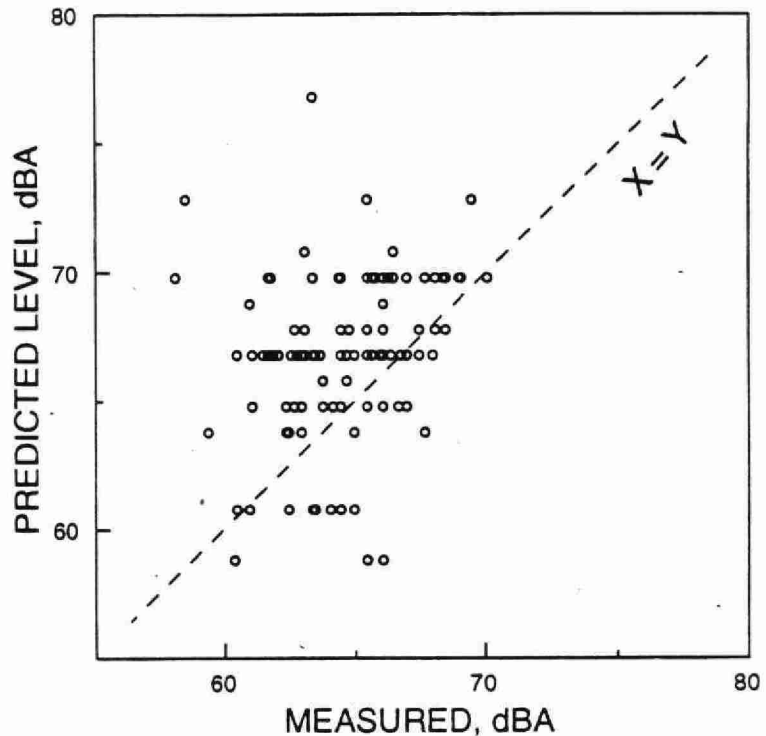
where

|       |                                                                                                                        |
|-------|------------------------------------------------------------------------------------------------------------------------|
| BELS  | is the ARI sound power rating in bells                                                                                 |
| -16.2 | converts to levels at 6 feet (1.83 m) from the source                                                                  |
| +3.0  | accounts for the first reflecting surface that is assumed to always be present                                         |
| NES   | is the number of extra reflecting surfaces within 10 feet of the unit (there is a 3 dB(A) increase for each of these). |

(In the ARI standard 275-84 procedure, the -16.2 and +3.0 terms are combined in their table 2.)

Measured and predicted source levels are compared in Figure 24. If the predictions were perfect, all data points would fall on the diagonal line labelled  $X = Y$ . There is considerable scatter; on average predicted values were 2.2 dB(A) larger than measured.

Figure 24. Predicted versus background-corrected measured source air conditioner A-weighted noise levels.



In examining the data in more detail, an apparent coding error in entering the number-of-extra-surfaces was found. For 60% of the cases there were, according to the data, no extra surfaces. Most domestic air conditioner units seem to be mounted on the ground within 10 feet of a wall and thus in most cases there would be at least one extra surface. Thus, it is not believable that more than a few cases had no extra surfaces. Two possible corrections were tried to attempt to guess the type of coding error that had been made. In one case, all the 0 extra surface values were changed to 1 extra surface, and in the other case all of the number of extra surface values were incremented by 1. When comparisons between measured and predicted values were made for each of these corrections, the mean errors were larger. When all 0 values were changed to 1 values, the mean error increased to approximately 4 dB(A), and when all number-of-extra-surface values were incremented by 1 the mean error increased to about 5 dB(A). Thus, it is reasonable to guess that even with the correct number of extra surfaces in each case there would be a mean error of approximately 3 to 4 dB(A) between measurement and prediction such that predictions would be on average larger.



There are three possible reasons for the method over-predicting the measured source levels:

- (1) The sound power ratings may have been incorrectly assigned to some units or the sound power ratings may not be correct;
- (2) the number-of-extra-surfaces correction in the ARI procedure may be an over-estimate of the actual effect of extra surfaces, or
- (3) the directional nature of the noise radiated by air conditioner units may lead to levels lower than predicted at positions to the side of the units where the source levels were always measured.

For the same 125 cases with ARI power ratings, the property-line air conditioner noise levels were also predicted. These were predicted from both the rated sound powers and from the measured source levels using the following equations based on the ARI 275-84 procedure.

Prediction from the rated sound power output:

$$\text{Predicted} = \text{BELS} \cdot 10 + 10 \cdot \log\{1/(4\pi r^2)\} + 3 \\ - \text{BARRIER} + \text{NES} \cdot 3 + \text{FACADE}, \text{ dB(A)} \quad (2)$$

Prediction from the measured mean source levels:

$$\text{Predicted} = \text{SOURCE} + 16.2 + 10 \log\{1/(4\pi r^2)\} \\ + \text{BARRIER} + \text{FACADE}, \text{ dB(A)} \quad (3)$$

where

BELS is the rated A-weighted sound power level, in bels

$10 \log\{1/(4\pi r^2)\}$  is the spherical spreading distance attenuation

$r$  = the source receiver distance, m

+3 is for the assumed first extra surface

BARRIER = the barrier attenuation as described below

NES = the number-of-extra surfaces within 10 feet of the unit

FACADE = is a correction for the microphone being near a reflecting surface (FACADE = 6 for the microphone at the facade, FACADE =

- 3 for the microphone within 10 feet of a reflecting surface )
- SOURCE = the mean measured source level 6 feet from the unit
- 16.2 converts the source level at 6 feet to a sound power level

The barrier attenuation from the ARI 275-84 procedure was approximated by the following equation for path differences,  $d$ , greater than 0.2 m:

$$\text{BARRIER} = 9.65 \log\{d\} + 7.07, \text{ dB(A)} \quad (4)$$

where  $d$  is the path difference between the path over or around the barrier, and the direct path through the barrier from the source to the receiver, m.

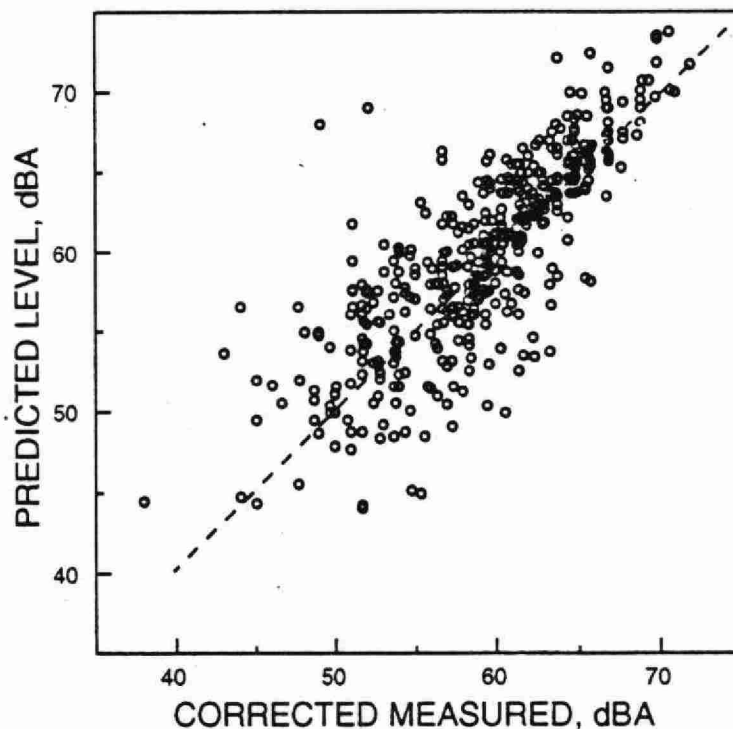
Because the measured property-line noise levels were often close to the background noise levels, the property-line levels were first corrected by subtracting the influence of the background levels. When these corrected property-line levels were predicted from the sound power ratings of the units, the mean error was similar to that for the prediction of the source levels ( 2.9 dB(A)). However, when these corrected property-line levels were predicted from the measured source levels, the mean error was only 0.7 dB(A). Thus, the same errors that limited the accuracy of the source level predictions seemed to similarly influence predictions of property-line levels, and the mean property-line levels could be predicted more accurately from the measured source levels.

## 9.2 Predictions from Measured Source Levels

Since the measured levels could be predicted more accurately from the measured source levels, further predictions were calculated from the measured source levels using all of the data and not just the 125 cases with rated sound power values. Those cases with data for two neighbours' air conditioners were excluded from the analyses, and in no cases were there data for more than two air conditioners. The measured levels at the property-line, at the facade, and at the patio were all corrected by subtracting the effect of the background noise levels. The resulting predictions using equations (3) and (4) above are compared with the corrected measurements in Figures 25 to 27. Table 9 summarizes the mean values, mean errors, and standard deviations for these comparisons.

At the property-line, levels were predicted with a mean error of 0.8 dB(A) and a standard deviation of 3.5 dB(A). Only 4 of the 434 cases in this analysis included a barrier attenuation, and in 49 of these cases there was a 3 dB(A) correction because the microphone was near a facade. Prediction errors must be due to the inaccuracy of the distance correction procedure from the source to the property-line and the influence of surfaces near the measuring microphone. Since the mean error is quite small, the average trend of the prediction is approximately correct. It is possible that a slightly smaller distance attenuation rate could reduce the mean error.

Figure 25. Predicted versus background-corrected measured property line air conditioner A-weighted noise levels.



The mean error of the facade level predictions shown in Figure 26 and Table 9 was 5.8 dB(A), which is much larger than for the other measurement positions. These measurements are different from the others in that the microphone was placed against the facade of the subject's home. This is expected to lead to a 6 dB(A) increase in levels and this factor is included in the predictions. However, the predictions are approximately 6 dB(A) too large. It is possible that these measurements were not all correctly made at the facade or that the measurement point was too close to the edge of the building. However, it seems unlikely that all 359 measurements were made incorrectly. The other alternative possibility is that the

+6 dB(A) facade correction is not appropriate. This too seems unlikely as other studies have established that this is a reasonably correct approach. Thus, the 5.8 dB(A) mean error cannot be explained.

Figure 26. Predicted versus background-corrected measured facade air conditioner A-weighted noise levels.

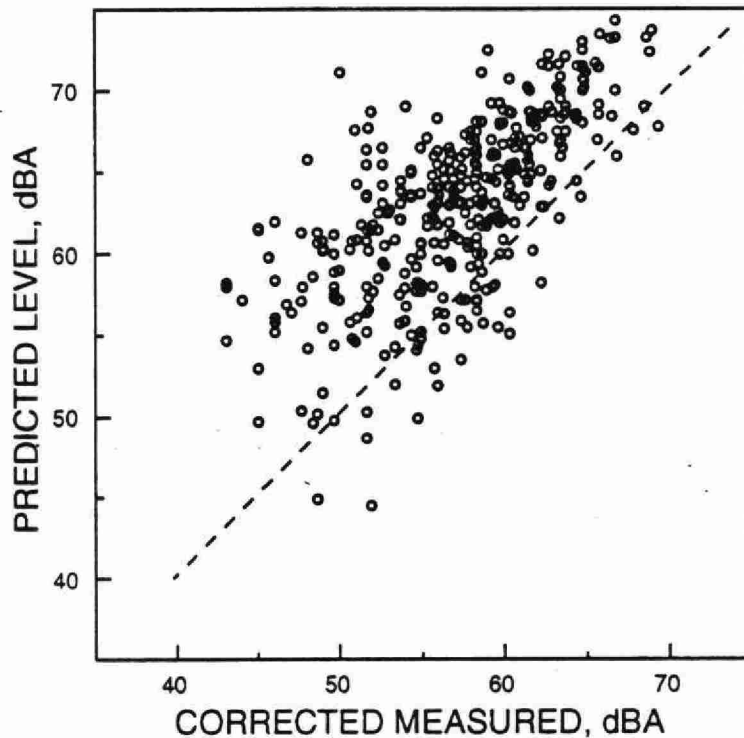


Figure 27 compares measured and predicted patio noise levels. From Table 9 it is seen that the mean error for these patio predictions was only 0.5 dB(A) and the standard deviation was 5.2 dB(A). Thus, there is a large amount of scatter in these predictions, but on average the prediction procedure seems to be approximately correct. This may be because only 5 of the 310 cases included barrier attenuations and only 13 of the 310 cases included a 3 dB(A) correction because the microphone was near to a facade. Thus, the predicted values depended mostly on attenuations with distance.

Figure 27. Predicted versus background-corrected measured patio air conditioner A-weighted noise levels.

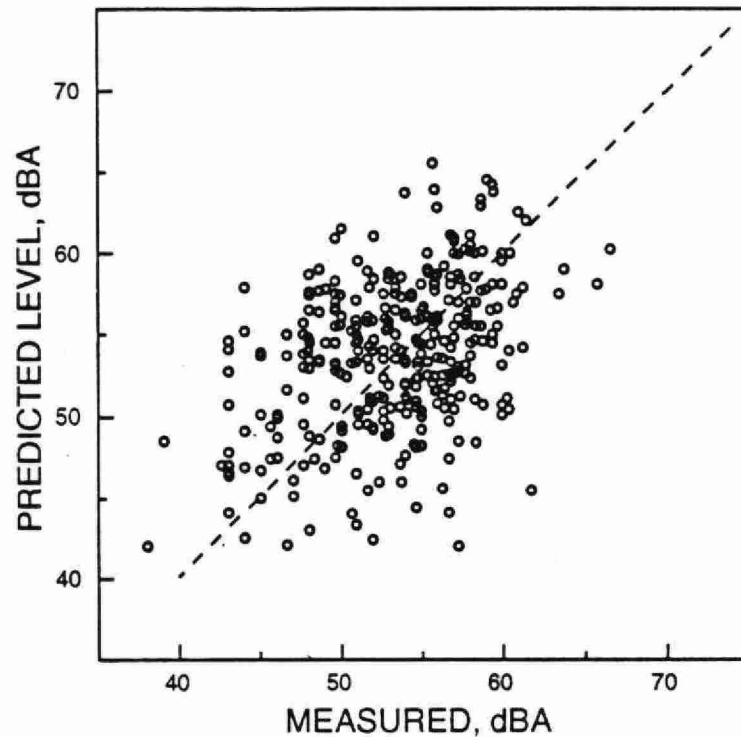


Table 9. Summary of comparison of measured and predicted levels, including the mean error of the predictions relative to the corrected measured values, and the standard deviation of predicted values about the corrected measured values.

|               | Number Measured values | Levels, dB(A) |                    | Predicted | Mean Error | Standard Deviation |
|---------------|------------------------|---------------|--------------------|-----------|------------|--------------------|
|               |                        | Measured      | Measured corrected |           |            |                    |
| Property line | 434                    | 60.7          | 59.2               | 60.0      | 0.8        | 3.5                |
| Facade        | 359                    | 59.2          | 57.2               | 63.0      | 5.8        | 5.5                |
| Patio         | 310                    | 56.5          | 53.3               | 53.8      | 0.5        | 5.2                |

### 9.3 Summary

Predictions using the ARI 275-84 procedure and based on the manufacturers ratings of the units over-predicted the measured source levels by at least 2 dB(A). The error is probably 3 to 4 dB(A), but errors in entering the values of the number-of-extra-surfaces make it impossible to be sure of the exact magnitude of the mean error. This over-prediction could be due to: (1) errors in the power rating of the units, (2) the influence of the directionality of the sound radiation from air conditioners at the source measuring positions, and (3) an exaggerated correction for the effect of extra surfaces near to the source.

Predictions of the levels at the property-line, at the facade, and at the patio made from the measured source levels do not include corrections for extra surfaces near the unit. For these predictions, the mean errors were small at the property-line and at the patio, but the mean error was approximately 6 dB(A) for facade

measurements. This large mean error could not be satisfactorily explained. The standard deviations of predicted values about measured values varied from 3.5 dB(A) to over 5 dB(A). Thus, these predictions were not particularly accurate.

## 10. Conclusions

The major conclusions of this report are summarized in the following points:

- (a) Measured air conditioner noise levels are often close to the existing background noise level from other sources. The average measured background level with no air conditioner noise from the present day-time measurements was 53 dB(A). Thus, it would often be impossible to measure lower air conditioner noise levels.
- (b) There were essentially no spontaneously mentioned adverse responses to air conditioner noise. However, subjects were, on average, prepared to pay 12% more for a very quiet central air conditioner.
- (c) Subjective responses to air conditioner noise were significantly related to measured noise levels, but the amount of variance explained was quite small. At air conditioner noise levels of up to 50 dB(A), virtually no one reported any annoyance to air conditioner noise. Even up to 55 dB(A), mean annoyance scores were very small.
- (d) Grouping responses to form composite response scales or rejecting responses at locations of very low signal/noise ratios were only partially successful in achieving stronger relations between objective and subjective responses.
- (e) Responses were in general more strongly related to signal/noise ratios than to the measured noise levels. There was virtually no indication of annoyance to air conditioner noise below a signal/noise ratio of +5 dB(A).
- (f) The frequency of hearing the neighbours' air conditioner tended to be related linearly with the objective noise measures.
- (g) Annoyance to the neighbours' air conditioner tended to be related to the cube of the objective noise measures.
- (h) Subject selection criteria were not optimally met and only 25% of the subjects did not own any type



of air conditioner. (It had been hoped to have 50% owners and 50% non-owners).

- (i) Ambient noise levels (as measured by  $L_{eq24}$ ) influenced responses by changing the signal/noise ratio, and thus signal/noise ratio measures would best predict these effects.
- (j) The effect of owning an air conditioner seemed to make respondents approximately 7 dB(A) less sensitive to their neighbours' air conditioner. This suggests that at sites where air conditioners are mandatory and all residents have air conditioners, outdoor air conditioner noise limits could be higher than for sites of mixed ownership. The present survey included a significant number of subjects from sites where air conditioners were mandatory.
- (k) Non-noise variables were significant predictors of adverse responses to air conditioner noise. In some cases these were predictable effects such as the effect of having windows open. In other cases, various socio-economic variables were more important predictors than noise measures. The importance of non-noise predictors is believed to be related to the fact that air conditioner noise levels were often not prominently above existing background noise levels.
- (l) The clearest relationships between subjective and objective responses were obtained from grouped data that would tend to average out individual differences. The percentage of subjects reporting hearing their neighbours' air conditioner were best related to the linear form of noise measures. The percentage of subjects that were annoyed by their neighbours' air conditioner noise were best related to the cube of the noise measures. Again, signal/noise ratios were better predictors of responses than the measured levels and annoyance did not increase until signal/noise ratios were greater than a threshold of about +5 dB(A).
- (m) The results of this report specifically include only daytime measurements of air conditioner noise in urban areas of metropolitan Toronto. Although sites would be quieter at night, these reduced night-time levels are usually strongly correlated with daytime levels. Thus, the reported night-time annoyance scores would probably correlate as well with daytime noise measurements as with night-time measurements.



There is evidence in the literature<sup>1</sup> that sensitivity to road traffic noise varies with community size. Thus, it is possible that the degree of disturbance to air conditioner noise may be different in very small or rural communities where ambient background noise levels could be lower.

- (n) The ARI 275-84 prediction scheme over-predicted the measured source levels by an amount estimated to be 3 dB(A) or more. Predictions of air conditioner noise levels at the facade of the neighbours' home were on average in error by 6 dB(A). Even where predictions were on average more accurate, the standard deviations about measured values were 3 to 5 dB(A).

The low air conditioner noise levels made the desired goals of the survey somewhere between difficult and impossible to achieve. To study peoples' response to a stimulus, a substantial detectable variation in the stimulus is necessary. The measurement results reported here indicate that the air conditioner noise stimulus was often masked or partially masked by existing background noise. Given this inherent difficulty in the basic concept of this experiment, the results must be concluded to be very successful, and to provide a large amount of useful information concerning subjective responses to neighbours' air conditioner noise.

## Reference

- (1) J.S. Bradley and B.A. Jonah, "The Effect of Site Selected Variables on Human Responses to Traffic Noise, Part III: Community Size by Socio-Economic Status by Traffic Noise Level", J. Sound and Vibr., Vol. 67, No. 3, pp. 409-423 (1979).

1. Subject number  
2(a). Interviewer number  
2(b). Site \_\_\_\_\_

Date \_\_\_\_\_  
Time \_\_\_\_\_

3. What things do you like MOST about your neighbourhood?

- (a) Air conditioning related comments  
(b) Quiet or lack of other noises  
(c) Other likes

4. What things do you dislike MOST about your neighbourhood?

- (a) Air conditioner noise  
(b) Other sources off noise  
(c) Other dislikes

5. In general, how considerate are your neighbours? (SHOW CARD !)

0    1    2    3    4    5    6    7  
NA   Not at all                      Medium                      Very

6. Do any of your immediate neighbours have central air conditioners or heat pumps?  
If NO, terminate interview and ask if they have such a unit.

7. During the DAY TIME (7:00 AM to 11:00 PM) when you are INDOORS:

- (a) How often do you hear ROAD TRAFFIC noise? ( 0, 1 to 7 )  
(b) How annoying is this ROAD TRAFFIC noise? ( 0, 1 to 7 )  
(c) How often do you hear AIRCRAFT noise? ( 0, 1 to 7 )  
(d) How annoying is this AIRCRAFT noise? ( 0, 1 to 7 )  
(e) How often do you hear noises from TRAINS? ( 0, 1 to 7 )  
(f) How annoying are these TRAIN noises? ( 0, 1 to 7 )  
(g) How often do you hear neighbour's AIR CONDITIONERS? ( 0, 1 to 7 )  
(h) How annoying are these AIR CONDITIONER noises? ( 0, 1 to 7 )

8. In the NIGHT TIME (11:00 PM to 7:00 AM) when you are INDOORS:

- (a) How often do you hear ROAD TRAFFIC noise? ( 0, 1 to 7 )  
(b) How annoying is this ROAD TRAFFIC noise? ( 0, 1 to 7 )  
(c) How often do you hear AIRCRAFT noise? ( 0, 1 to 7 )  
(d) How annoying is this AIRCRAFT noise? ( 0, 1 to 7 )  
(e) How often do you hear noises from TRAINS? ( 0, 1 to 7 )  
(f) How annoying are these TRAIN noises? ( 0, 1 to 7 )  
(g) How often do you hear neighbour's AIR CONDITIONERS? ( 0, 1 to 7 )  
(h) How annoying are these AIR CONDITIONER noises? ( 0, 1 to 7 )

.....

9. During the DAY TIME (7:00 AM to 11:00 PM) when you are OUTDOORS:

- (a) How often do you hear ROAD TRAFFIC noise? ( 0, 1 to 7 )
  - (b) How annoying is this ROAD TRAFFIC noise? ( 0, 1 to 7 )
  - (c) How often do you hear AIRCRAFT noise? ( 0, 1 to 7 )
  - (d) How annoying is this AIRCRAFT noise? ( 0, 1 to 7 )
  - (e) How often do you hear noises from TRAINS? ( 0, 1 to 7 )
  - (f) How annoying are these TRAIN noises? ( 0, 1 to 7 )
  - (g) How often do you hear neighbour's AIR CONDITIONERS? ( 0, 1 to 7 )
  - (h) How annoying are these AIR CONDITIONER noises? ( 0, 1 to 7 )
- .....

10. During the NIGHT TIME (11:00 PM to 7:00 AM) when you are OUTDOORS:

- (a) How often do you hear ROAD TRAFFIC noise? ( 0, 1 to 7 )
  - (b) How annoying is this ROAD TRAFFIC noise? ( 0, 1 to 7 )
  - (c) How often do you hear AIRCRAFT noise? ( 0, 1 to 7 )
  - (d) How annoying is this AIRCRAFT noise? ( 0, 1 to 7 )
  - (e) How often do you hear noises from TRAINS? ( 0, 1 to 7 )
  - (f) How annoying are these TRAIN noises? ( 0, 1 to 7 )
  - (g) How often do you hear neighbour's AIR CONDITIONERS? ( 0, 1 to 7 )
  - (h) How annoying are these AIR CONDITIONER noises? ( 0, 1 to 7 )
- .....

- .....
- \_\_\_\_\_ 11. How often does ROAD TRAFFIC noise interfere with your SLEEP? ( 0, 1 to 7 )
- \_\_\_\_\_ 12. How often does AIRCRAFT noise interfere with your SLEEP? ( 0, 1 to 7 )
- \_\_\_\_\_ 13. How often does TRAIN noise interfere with your SLEEP? ( 0, 1 to 7 )
- \_\_\_\_\_ 14. How often does neighbour's AIR CONDITIONER noise interfere with your SLEEP?  
( 0, 1 to 7 )
- .....

- \_\_\_\_\_ 15. In which room of your home is your neighbour's air conditioner noise most disturbing?  
(0) none, (1) kitchen, (2) living room, (3) dining room, (4) bedroom, (5) bathroom, (6) other
- \_\_\_\_\_ 16. Do you have, (a) A central air conditioner? (1=Yes, 2=No)  
\_\_\_\_\_ (b) A window air conditioner? (1=Yes, 2=No)
- \_\_\_\_\_ 17. If you were buying a \$2,000. central air conditioner, how much  
EXTRA would you be prepared to spend for a very quiet model?
- \_\_\_\_\_ 18. At this time of year, do you normally have some windows open? (1=Yes, 2=No)
- \_\_\_\_\_ 19. How many adults ( 18 years or older) live in this home?
- \_\_\_\_\_ 20. How many young people (< 18 years) live in this home?
- \_\_\_\_\_ 21. Into which category would your age belong?  
19 to 30    31 to 40    41 to 50    51 to 60    61 and up
- \_\_\_\_\_ 22. Into which category would your total family income fit?  
0 to 20,000    21 to 40,000    41 to 60,000    61,000 to 80,000    81,000 and up
- \_\_\_\_\_ 23. How much formal education have you completed?  
elementary school (8)    part high school (10)  
high school (13)    some college or university (14)  
completed first degree (16)    postgraduate studies (19)

Don't forget to ask which neighbours have central air conditioners or heat pumps.

.....

- \_\_\_\_\_ 24. Is the subject, (1) Male, or (2) Female?
- \_\_\_\_\_ 25. Did the subject appear to have any hearing problems? (1=Yes, 2=No)
- \_\_\_\_\_ 26. Is the home, (1) Row housing (more than 2 homes joined together)?  
(2) Semi-detached (2 homes joined together)?  
(3) Detached home?
- .....

# NOISE MEASUREMENT RESPONSE SHEET

## UNIT 1. A-Weighted Air Conditioner levels from 30 second integrated measurements

### (a) SOURCE LEVELS (measured 6 feet from the unit and 3-4 feet above ground)

- (1) \_\_\_\_\_ dBA (4) Make \_\_\_\_\_  
 (2) \_\_\_\_\_ dBA (5) Model \_\_\_\_\_  
 (3) \_\_\_\_\_ dBA (6) Serial No. \_\_\_\_\_

|                                                             | Distances<br>from Air<br>Conditioner<br>a      b | Number<br>Extra<br>Surfaces | Perpendicular<br>Barrier<br>Height | Microphone<br>re.<br>Facade |
|-------------------------------------------------------------|--------------------------------------------------|-----------------------------|------------------------------------|-----------------------------|
| (b) AT RESPONDENTS HOME.                                    |                                                  |                             |                                    |                             |
| (7) _____ dBA (at property line)                            | _____ ft                                         | _____                       | _____ ft                           | _____                       |
| (8) _____ dBA (at facade of home)                           | _____ ft                                         | _____                       | _____ ft                           | _____ 6 _____               |
| (9) _____ dBA (at outdoor use area)<br>(e.g. patio or deck) | _____ ft                                         | _____                       | _____ ft                           | _____                       |
| (10) _____ dBA (air conditioner off)                        | _____ ft                                         | _____                       | _____ ft                           | _____                       |

## UNIT 2. A-Weighted Air Conditioner levels from 30 second integrated measurements

### (a) SOURCE LEVELS (measured 6 feet from the unit and 3-4 feet above ground)

- (1) \_\_\_\_\_ dBA (4) Make \_\_\_\_\_  
 (2) \_\_\_\_\_ dBA (5) Model \_\_\_\_\_  
 (3) \_\_\_\_\_ dBA (6) Serial No. \_\_\_\_\_

|                                                             | Distances<br>from Air<br>Conditioner<br>a      b | Number<br>Extra<br>Surfaces | Perpendicular<br>Barrier<br>Height | Microphone<br>re.<br>Facade |
|-------------------------------------------------------------|--------------------------------------------------|-----------------------------|------------------------------------|-----------------------------|
| (b) AT RESPONDENTS HOME.                                    |                                                  |                             |                                    |                             |
| (7) _____ dBA (at property line)                            | _____ ft                                         | _____                       | _____ ft                           | _____                       |
| (8) _____ dBA (at facade of home)                           | _____ ft                                         | _____                       | _____ ft                           | _____ 6 _____               |
| (9) _____ dBA (at outdoor use area)<br>(e.g. patio or deck) | _____ ft                                         | _____                       | _____ ft                           | _____                       |
| (10) _____ dBA (air conditioner off)                        | _____ ft                                         | _____                       | _____ ft                           | _____                       |

### UNIT 3. A-Weighted Air Conditioner levels from 30 second integrated measurements

(a) SOURCE LEVELS (measured 6 feet from the unit and 3-4 feet above ground)

- (1) \_\_\_\_\_ dBA (4) Make \_\_\_\_\_  
 (2) \_\_\_\_\_ dBA (5) Model \_\_\_\_\_  
 (3) \_\_\_\_\_ dBA (6) Serial No. \_\_\_\_\_

(b) AT RESPONDENTS HOME.

- |                                                             | Distances<br>from Air<br>Conditioner<br>a      b | Number<br>Extra<br>Surfaces | Perpendicular<br>Barrier<br>Height | Microphone<br>re.<br>Facade |
|-------------------------------------------------------------|--------------------------------------------------|-----------------------------|------------------------------------|-----------------------------|
| (7) _____ dBA (at property line)                            | _____ ft                                         | _____                       | _____ ft                           | _____                       |
| (8) _____ dBA (at facade of home)                           | _____ ft                                         | _____                       | _____ ft                           | _____ 6 _____               |
| (9) _____ dBA (at outdoor use area)<br>(e.g. patio or deck) | _____ ft                                         | _____                       | _____ ft                           | _____                       |
| (10) _____ dBA (air conditioner off)                        | _____ ft                                         | _____                       | _____ ft                           | _____                       |

### LOCAL ROAD TRAFFIC OR OTHER BACKGROUND NOISE

24 hour measures

- (1) \_\_\_\_\_ LEQD  
 (2) \_\_\_\_\_ LEQN  
 (3) \_\_\_\_\_ LEQ24

- (4) L<sub>1</sub> \_\_\_\_\_ dBA  
 (5) L<sub>10</sub> \_\_\_\_\_ dBA  
 (6) L<sub>50</sub> \_\_\_\_\_ dBA  
 (7) L<sub>90</sub> \_\_\_\_\_ dBA  
 (8) L<sub>99</sub> \_\_\_\_\_ dBA  
 (9) L<sub>EQ</sub> \_\_\_\_\_ dBA

(10) \_\_\_\_\_ ft Distance from 24 hour measurement point to centre of closest lane of road traffic.

(11) MAJOR source of background noise.

- (1) Road traffic  
 (2) Trains  
 (3) Aircraft  
 (4) Construction  
 (5) Air conditioners  
 (6) Other (specify) \_\_\_\_\_

(12) Other audible source

- (1) Road traffic  
 (2) Trains  
 (3) Aircraft  
 (4) Construction  
 (5) Air conditioners  
 (6) Other (specify) \_\_\_\_\_

Sketch a site plane on the reverse of this page. Include: measured air conditioners, houses, property lines, measurement positions, and large obstacles.

## **APPENDIX 2 - Statement of Work**

### **PROPOSAL FOR AIR CONDITIONER NOISE SURVEY**

#### **1. INTRODUCTION**

This proposal describes a shared research project where the Acoustics Section of the Institute for Research in Construction (IRC) of the National Research Council would act as the principal consultant on a project carried out for the Heating Refrigerating and Air Conditioning Institute of Canada (HRAI) in cooperation with the Ontario Ministry of the Environment. IRC would develop the overall experimental design, the physical measurement procedures, and the questionnaire for the survey in consultation with the other parties and so that the survey meets the needs of the other parties. IRC would share the costs of the project and would analyze the results and provide a final report outlining these results for HRAI. IRC would retain the right to use results in technical publications or other research studies so that the survey may be of more wide spread benefit.

#### **2. OBJECTIVES**

The survey would serve three main objectives:

- (a) To relate residents survey responses to measured outdoor air conditioning unit noise levels for cases of varied background noise levels and for cases where the respondents either had or did not have an air conditioning unit themselves.
- (b) To relate measured outdoor air conditioning unit noise levels to the type, make, age, and installation of the air conditioning unit.
- (c) To test the accuracy of the ARI Standard 275-84 for estimating A-weighted sound levels from air conditioning units.

#### **3. EXPERIMENTAL DESIGN**

It is proposed that 500 subjects be interviewed and their neighbours' air conditioning units each be measured. While the primary independent variable is the incident air conditioner noise level, two other variables are expected to be important predictor variables and would be used to determine the selection of sites. The ambient background noise levels, usually determined by the local road traffic noise, would limit subjects ability to hear air conditioning unit noise and are therefore an important predictor variable. Also, whether or not the subject has air conditioning himself is expected to influence his or her responses. Thus, the 500 subjects would be chosen to form a matrix of 4 groups of 125 subjects each, as



indicated in Figure 1. below. For each of the 4 site selection groups, analyses could examine subjects responses as a function of air conditioner noise levels. Other analyses could be performed on the complete set of 500 responses.

Figure 1. Site Selection  
Experimental Design

|                                                                  |                                                                   |
|------------------------------------------------------------------|-------------------------------------------------------------------|
| Low Background Noise Level<br>Respondent has Air Conditioning    | High Background Noise Level<br>Respondent has Air Conditioning    |
| Low Background Noise Level<br>Respondent has no Air Conditioning | High Background Noise Level<br>Respondent has no Air Conditioning |

#### 4. QUESTIONNAIRE

The questionnaire would be presented to respondents as concerning the neighbourhood environment. In the interests of efficiency and of ensuring maximum respondent cooperation, the questionnaire would be kept as short as possible. Questions would be included in 3 main subject areas.

- (a) There would be the normal general and demographic questions, perhaps including a general question concerning how noisy it is in their neighbourhood.
- (b) There would be specific questions to assess the audibility and disturbance of road traffic and other background outdoor noises, for indoor and outdoor locations, and for day and night hours.
- (c) Parallel questions would assess the audibility and disturbance of outdoor air conditioner noise at indoor and outdoor locations and for day and night hours. Questions would be included to determine the most sensitive location and whether windows are normally open or closed.

A final question could elicit a direct comparison of the effects of air conditioner and road traffic noise. Where possible responses, would be obtained on 7-point response scales to permit comprehensive statistical analyses of the data.

#### 5. PHYSICAL MEASUREMENTS

A detailed measurement protocol would be developed in cooperation with the other parties. It is envisioned that A-weighted level measurements would be made at two or three locations close to the source (approximately 2 m). Where possible, A-weighted level measurements would also be made at the survey respondents outdoor living area (such as a patio) and at the facade of his home close to the neighbour's air conditioning unit. A-weighted level measurements could also be made at the property line.

It is anticipated that in many cases these measurements will not be possible due to high levels of other noises such as local road traffic noise. It is therefore proposed that in all cases noise levels be estimated using the ARI Standard 275-84. This will ensure complete noise level data for all respondents. Where both measurements and estimates are made, the data can also be used to evaluate the ARI Standard procedure.

Measurements of the existing background noise levels are also required, and must be an accurate indicator of the noise climate around the subjects' home. Such noise levels will normally be due to local road traffic noise that can vary considerably throughout a 24-hour period. It is therefore proposed to measure 24-hour road traffic statistical levels at the same point on the facade of the respondents home and to use L90 values as an indicator of the residual road traffic noise.

Personnel making the air conditioner noise level measurements would also record the required information from the air conditioning unit name plate, and make site measurements for the calculations to estimate air conditioner noise levels according to the ARI Standard.

## **6. RESPONSIBILITIES**    IRC would:

- (a) develop and pretest the questionnaire, and develop instructions for the interviewers using the questionnaire. IRC would participate in a one-day training session for the interviewers.
- (b) provide software for the entry of all data using IBM PC compatible computers.
- (c) develop guidelines for physical measurements (in cooperation with the other parties), and for the estimation of air conditioner noise levels using the ARI Standard.
- (d) carry out statistical analyses of the acquired data using the Statistical Package for Social Sciences.
- (e) provide a final report based on these analyses and interpret the effect of various parameters on the disturbance caused by air conditioning unit outdoor noise.

HRAI (and other parties) would:

- (a) hire and train personnel to carry out the interviewing, noise measurements, ARI calculations, and data entry for the survey.
- (b) provide transportation for these personnel to the measurement sites.
- (c) provide all noise measurement instrumentation for the survey.
- (d) provide administrative support for the field personnel and supply computer facilities for the entry of data so that the data is given to IRC in a form that can be read by an IBM PC compatible computer.
- (e) locate sites for the survey that meet their requirements and the requirements of the experimental design of this proposal.



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